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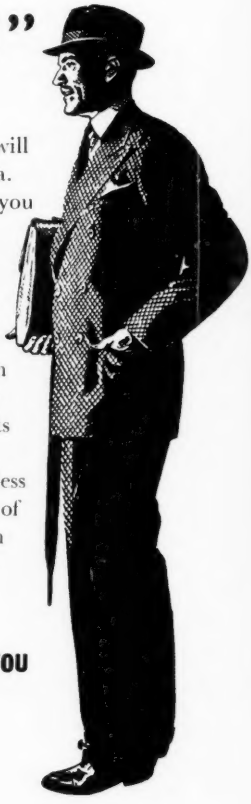

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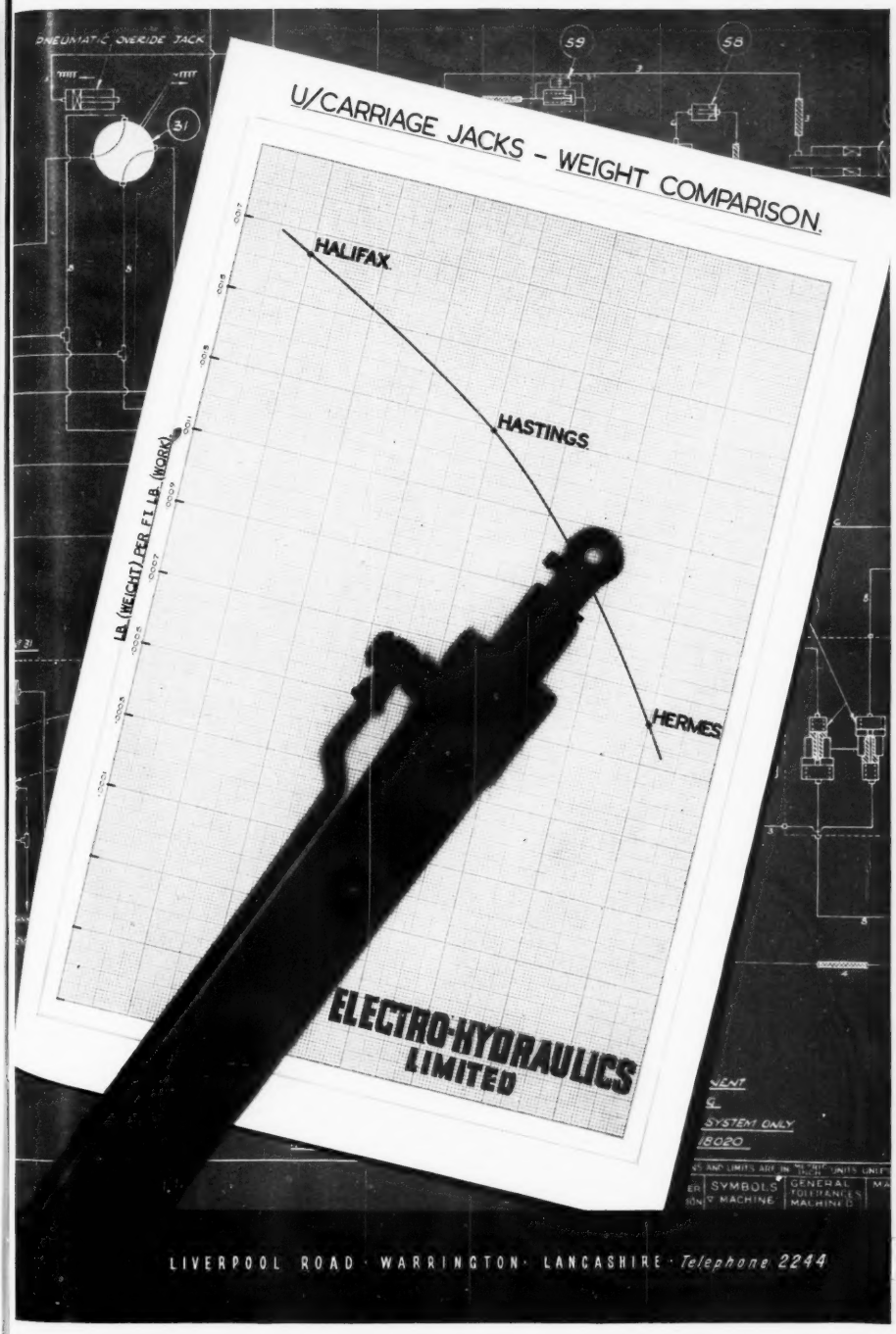
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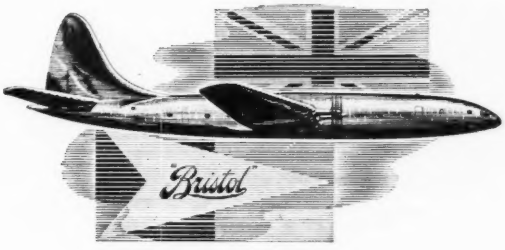

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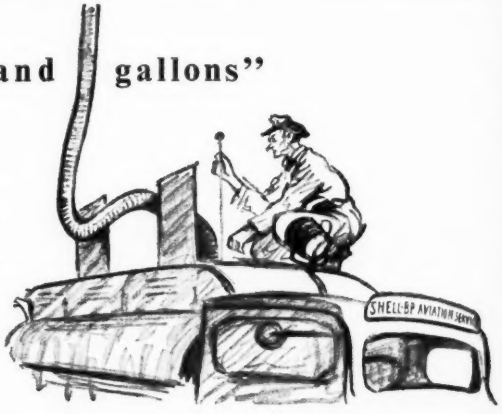

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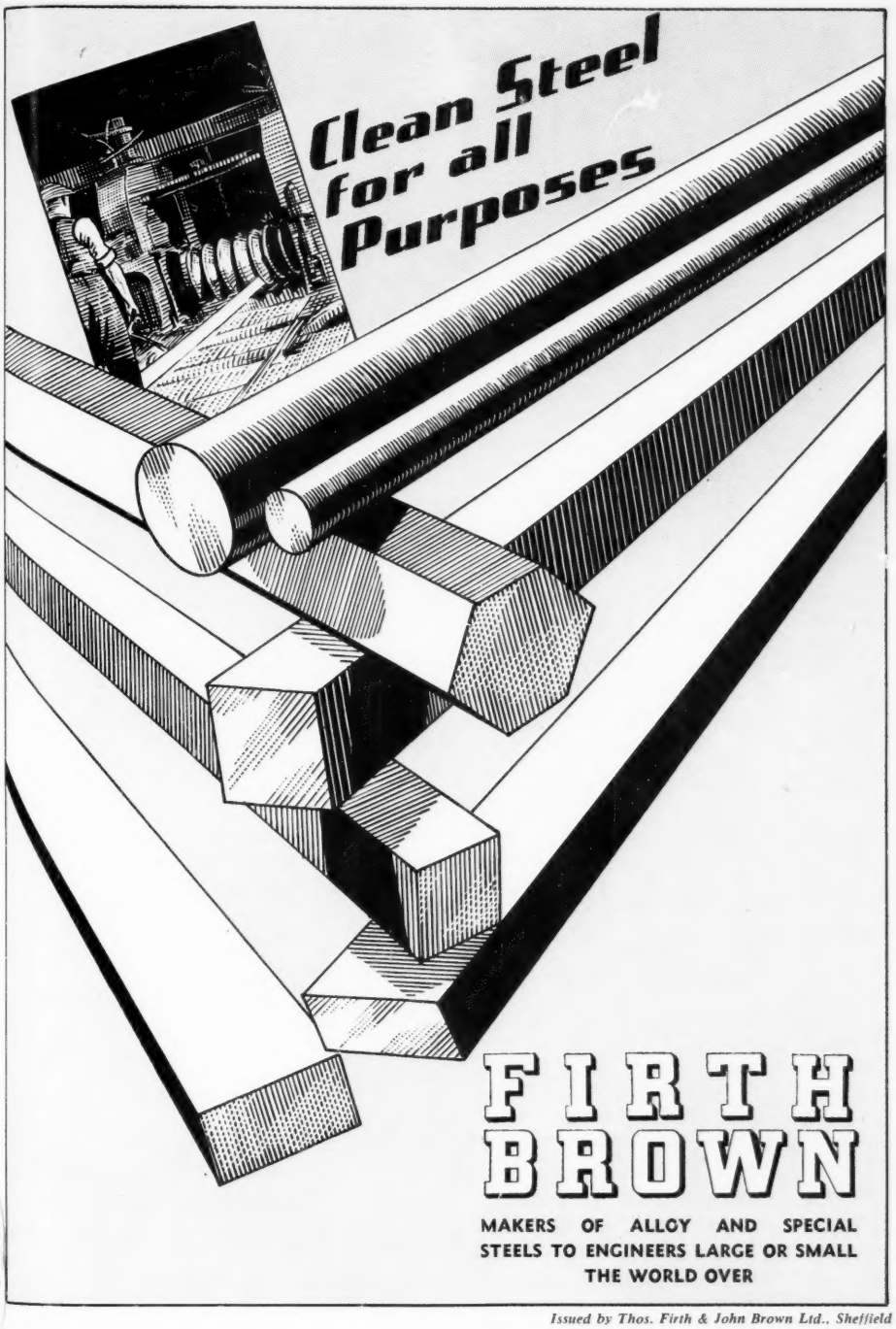

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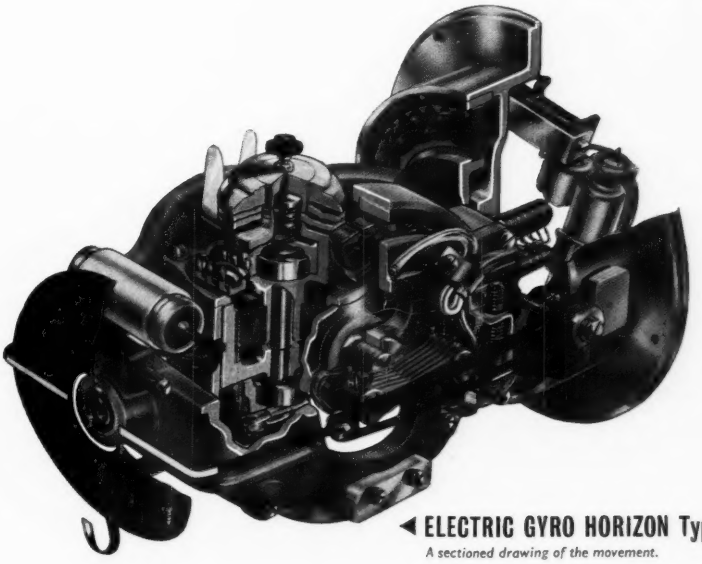

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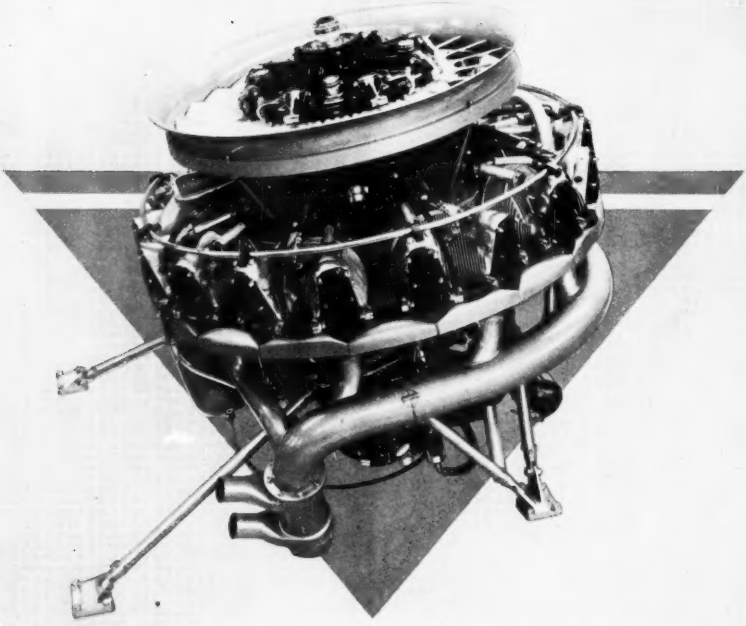

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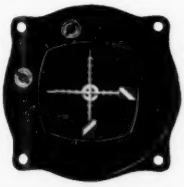

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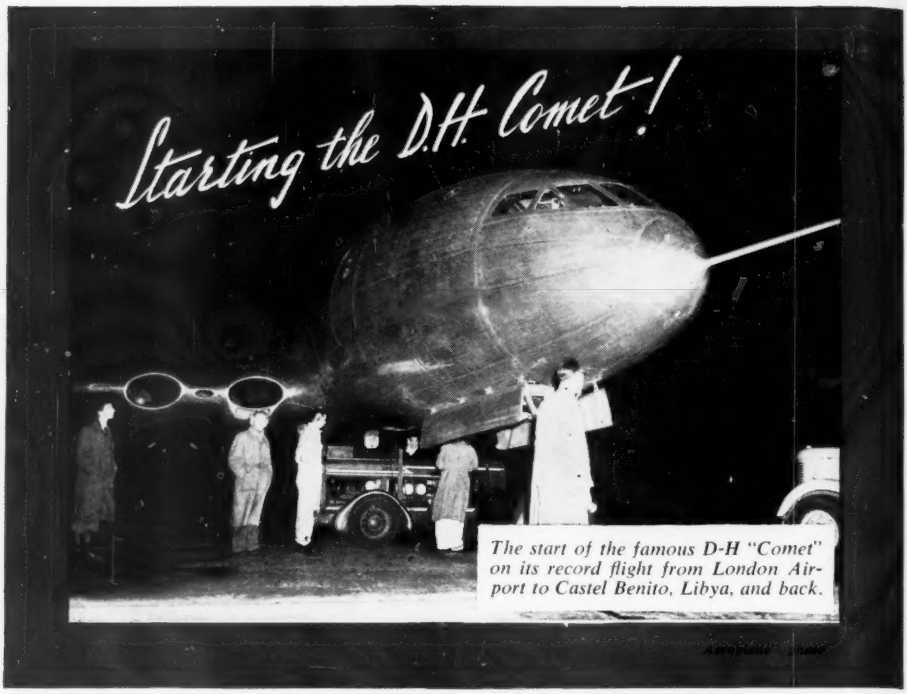

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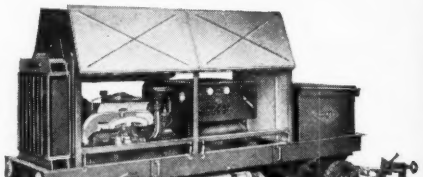

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AERODYNAMIC BALANCING OF PROPELLERS

by

H. L. MILNER, Wh.Sc., A.M.I.C.E., F.R.Ae.S.

DESPITE the high standard of workmanship employed in its fabrication, a propeller, like any other manufactured article, invariably differs from the ideal product in some respect which may, or may not, be of functional significance according to the nature of the disparity. The component blades of a propeller are no exception to this rule and it is the author's object to examine the consequences of dimensional deviations of the actual blades from those of an assumed standard and to describe apparatus devised to minimise or eliminate the most undesirable of them, namely, the tendency to induce vibration in the aircraft. From the earliest day, aircraft vibration has been attributed to the engine propeller combination and has come to be regarded as an inevitable characteristic. It can be demonstrated, however, that where aerodynamically balanced blades are employed, vibration difficulties are not an inherent property of the propeller. This is a matter of considerable importance to the turbo-propeller in which the prime mover is virtually vibrationless and consequently any unbalance of the propeller would be thrown into prominence.

Quite independently the problem of aerodynamic unbalance has been investigated both in America and Britain. The present article concerns the British development done by Rotol Limited but at the outset it will be of interest to consider briefly the American line of approach to the problem, because the two methods have nothing in common except the final goal, elimination of vibration. A detailed account of the American method appeared in *Aircraft Engineering*, December 1941, "Dynamic Balancing of Airscrews," by M. C. Beebe. In this, after disposing of several different suggestions as being either too complicated or impracticable, the author described equipment which was actually built, but to what extent it was used is unknown.

The adopted scheme comprises a non-rotating vertical diaphragm mounted on elastically supported vertical pivots in the wake of the propeller and extending beyond the propeller disc. The diaphragm is composed of a porous screen carried by the pivoted framework to permit a certain amount of axial flow and so reduce the radial flow which would result from the use of an impervious diaphragm. The whole diaphragm can oscillate within limits about a vertical axis and an electrical pick-up arranged at each end of the horizontal diameter translates any oscillatory motion of the diaphragm into electric pulses. With the propeller rotating in front of the diaphragm any variation of thrust moment between the component blades will throw a kind of shadow of this variation on to the diaphragm, so that the electric impulses become a measure of the aerodynamic unbalance. An auxiliary phasing device synchonised with the propeller rotation serves to identify the oscillatory motion of the diaphragm with the corresponding blade. Thus the magnitude and angular location of the aerodynamic unbalance can be determined.

By selecting one blade of the propeller as a reference, or master blade, the apparatus will indicate differences in thrust moment of the individual blades which can be translated in terms of the pitch corrections required to establish aerodynamic balance. It is clear that the method is confined to thrust moment balance only under the conditions of test, which scarcely approximate to those of flight. and is incapable of dealing with the torque force balance to be defined later and which

Paper received June 1949.

Mr. Milner is Project Engineer with Rotol Ltd.

experience has shown to be often more important than thrust balance alone. Furthermore, the method suffers from the necessity of rotating the propeller under power, a feature which is avoided in the Rotol system of aerodynamic balancing which will now be discussed.

At an early stage of the late war repeated complaints of severe aircraft vibration led to an investigation of its possible causes, and vibrograph records taken in flight proved that much of the vibration was excited by the propeller. This was clear because the frequency of the vibration in most cases coincided with the propeller rotational speed, an indication of some unbalanced force rotating with the propeller. A critical review of the processes employed in propeller manufacture ruled out the likelihood of dynamic unbalance being the source of vibration, so attention was turned to the possibility of aerodynamic unbalance providing the disturbing force. An analysis of the change in the aerodynamic forces acting on a blade due to an assumed distribution of angular errors, indicated possible increments of force which were of appreciable magnitude, even when the assumed errors were within the permissible manufacturing tolerances. Consequently a propeller composed of blades chosen at random could be expected to produce an unbalanced resultant force, the elimination of which is essential for the propeller to be in a state of aerodynamic balance. The components of the disturbing forces acting on a propeller in the flight direction and in the plane of rotation have to be treated separately. Thus two cases arise; these are defined as thrust moment balance and torque force balance, the relative significance of which, as will be explained later, depends upon the dynamic characteristics of the installation, including the airframe. For brevity it is convenient to refer to these cases as thrust balance and torque balance respectively.

Resolving the resultant air load acting on an elementary length of blade into two components dT and dQ in the thrust and torque planes respectively, the necessary conditions to be satisfied for the propeller to have inherent aerodynamic balance are:—

$$(1)\quad \Sigma r dT = A, \qquad (2)\quad \Sigma dQ = B$$

where r is the radius of the blade element, A and B are constants common to all the blades of the propeller and the summation is taken over the length of the blade.

Condition (1) implies equality of the thrust moments about axial planes containing the propeller shaft and normal to the respective blade axes. When this equality is not

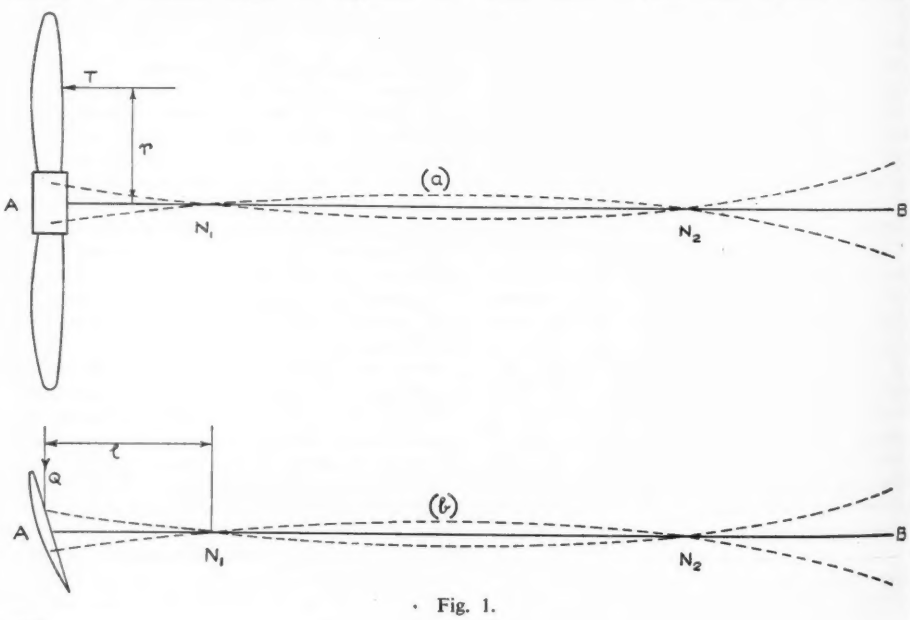

Fig. 1.

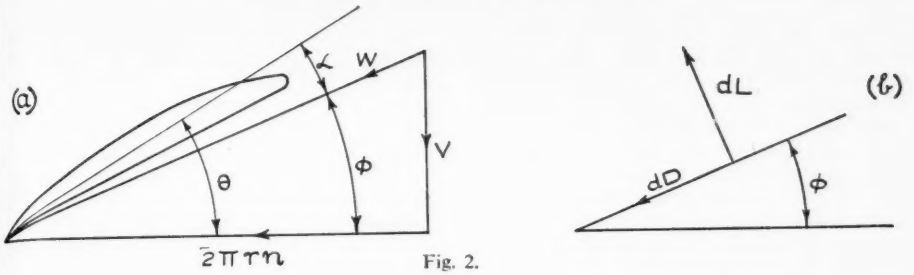

Fig. 2.

achieved there will be a resultant unbalanced couple rotating with the propeller.

Condition (2) requires equality of the sum of the component forces acting in the plane of rotation for each blade. Where this condition is not satisfied there will be a resultant unbalanced force acting laterally on the propeller shaft and rotating with it.

In general, it is not possible to satisfy either of these conditions when all the blades are set at some common pitch angle, but by differential pitch setting either type of balance can be secured, but not both simultaneously. This is because of the fortuitous nature of the errors of manufacture and the fact that the forces producing the two types of unbalance are mutually perpendicular. Fortunately the pitch corrections required to remove either type of unbalance usually assist in partially correcting the other type, leaving a more or less important residue of unbalanced couple or force as the case may be.

The disturbing effect of the unbalanced residue, except when very large forces are involved, would pass unnoticed in the absence of resonance with the airframe. Most airframes do resonate at frequencies within the range of propeller speeds and the question of the type of balance to be adopted in any particular case largely depends upon the vibration characteristics of the airframe. To illustrate this point consider the airframe replaced by a straight beam of similar dynamic properties so that the centre line of the beam approximates to that of, say, the fuselage. The lowest mode of vibration of such a beam will be as shown in Fig. 1(*a*) with a node at some distance from each end. The beam at rest is represented by the straight line *AB* and when vibrating by the broken lines with nodes at N_1, N_2.

The unbalanced thrust of the propeller is represented by a force *T* at radius *r*. Thus the beam is subject to a periodic couple of amplitude *Tr* rotating at propeller speed, and if the periodicity of the rotating couple coincides with the natural frequency of the beam the latter will vibrate as indicated. It should be noted that the moment of the force *T* is the same about any point in *A B*, thus its moment about the nearest node is independent of the position of N_1.

The capacity of a force to excite vibration in a dynamic system of the type under consideration depends upon its moment about the adjacent node, and in the case of thrust forces this is constant for all nodal positions. On the other hand, response to forces in the torque plane is not independent of the position of the node. *Q* in Fig. 1(*b*) represents an unbalanced torque force. Its moment about N_1 is *Ql* and if the position of the node is such that the moment of the unbalanced torque force is greater than that of the unbalanced thrust, *i.e. Ql* is greater than *Tr*, then torque unbalance will be more noticeable than thrust unbalance.

The relative importance of the two types of unbalance thus depends upon the distance between the first node and the propeller disc and hence on the dynamic characteristics of the airframe. Further, it is not merely the nodal distance which is the deciding factor but the moment of the thrust or torque force about the node. The ratio of *Q* to *T* increases with the flight speed and similarly, the corresponding moments about the nodal point change, so it is to be expected that a preference for torque balance will be shown on high speed aircraft having an appreciable distance between the propeller disc and the first node.

The possible modes of vibration of an aeroplane are much more complex than those of the simple system just described, of which only the fundamental mode has been considered, but the analogy is useful in illustrating the essential difference between thrust and torque unbalance.

In an analysis of the effect of errors of manufacture on the potential unbalance of a propeller blade, it is convenient to visualise as a standard of comparison an idealised blade, *i.e.* one which is physically perfect in form and dimensions, and to determine under what conditions the two blades, actual and idealised, could be aerodynamically balanced. For this purpose it is sufficient to adopt the simple blade-element theory of propeller action.

Consider the forces acting on a blade element at radius r and length dr. Fig. 2(*a*) represents the cross section of the blade element and the components of velocity. Fig. 2(*b*) represents the corresponding components of force acting on the element.

NOTATION

n = angular velocity of the propeller
V = Forward speed of flight
W = Resultant air velocity relative to the blade element
α = angle between the zero lift line of the section and direction of W (angle of incidence)
θ = angle of zero lift line relative to the plane of rotation
$\phi = \theta - \alpha$
dL = Lift force on the element
dD = Drag force on the element
C = chord of the section.

The forces on the element are related to the quantities represented in Fig. 2 by the following equations:—

$$dL = \tfrac{1}{2}\rho W^2 C_L C\, dr \quad . \quad . \quad (1)$$

$$dD = \tfrac{1}{2}\rho W^2 C_D C\, dr \quad . \quad . \quad (2)$$

Where C_L and C_D are lift and drag coefficients of the blade section and ρ is the air density, the axial thrust dT of the element is given by the components of these forces parallel to the axis of rotation.

$$dT = \tfrac{1}{2}\rho C W^2 (C_L \cos\phi - C_D \sin\phi)\, dr$$

$$= 2\pi^2 r^2 n^2 \rho C (C_L \cos\phi - C_D \sin\phi) \sec^2\phi dr \quad . \quad . \quad . \quad . \quad (3)$$

Similarly the torque force dQ due to the element is the component force in the plane of rotation and perpendicular to the blade axis

$$dQ = 2\pi^2 r^2 n^2 \rho C (C_L \sin\phi + C_D \cos\phi) \sec^2\phi dr \quad . \quad . \quad . \quad . \quad (4)$$

Now C_D is a small quantity compared with C_L and, over the range of angles of incidence associated with optimum performance of the propeller, is substantially constant.

Also, $C_L = m\alpha$ where m is some constant.

Hence, neglecting terms containing C_D and substituting for C_L the moment of the thrust component about a plane containing the axis of rotation and perpendicular to the blade axis is

$$dM = rdT = 2\pi^2 n^2 \rho m \alpha C r^3 \sec\phi dr \quad . \quad (5)$$

and similarly

$$dQ = 2\pi^2 n^2 \rho m \alpha C r^2 \tan\phi \sec\phi dr \quad . \quad (6)$$

If R denotes the tip radius of the propeller and $J = V/2nR$, by introducing $x = r/R$, these equations may be written

$$dM = K_1 C \alpha x^2 (x^2 + J^2/\pi^2)^{\frac{1}{2}}\, dx \quad . \quad (7)$$

$$dQ = K_2 C \alpha (x^2 + J^2/\pi^2)^{\frac{1}{2}}\, dx \quad . \quad (8)$$

where K_1 and K_2 are constants for the blade.

The change in thrust moment due to a change $\delta\alpha$ in the angle of incidence extending over a blade segment bounded by radii ξ_1 and ξ_2 is given by

$$\delta M = K_1 \delta\alpha \int_{\xi_1}^{\xi_2} C x^2 (x^2 + J^2/\pi^2)^{\frac{1}{2}}\, dx$$

Imagine the blade divided into segments bounded by sections at radii ξ_1, ξ_2, ξ_3 - - - - in which the angular errors of the zero lift line are $\delta\alpha_1$, $\delta\alpha_2$, $\delta\alpha_3$, and so on, respectively, the excess of thrust moment over that of the ideal blade will be, with due regard to sign,

$$\delta M = K_1 \delta\alpha_1 \int_{\xi_1}^{\xi_2} C x^2 (x^2 + J^2/\pi^2)^{\frac{1}{2}}\, dx +$$

$$+ K_1 \delta\alpha_2 \int_{\xi_2}^{\xi_3} C x^2 (x^2 + J^2/\pi^2)^{\frac{1}{2}}\, dx + \quad . \quad (9)$$

But the same change in thrust moment could be brought about by rotating the ideal blade through some angle $\Delta\theta$ say. Conversely the combined errors $\delta\alpha$ can be nullified by reducing the pitch of the actual blade by $\Delta\theta$ Hence

$$\delta M = K_1 \Delta\theta \int_0^1 C x^2 (x^2 + J^2/\pi^2)^{\frac{1}{2}}\, dx \quad . \quad (10)$$

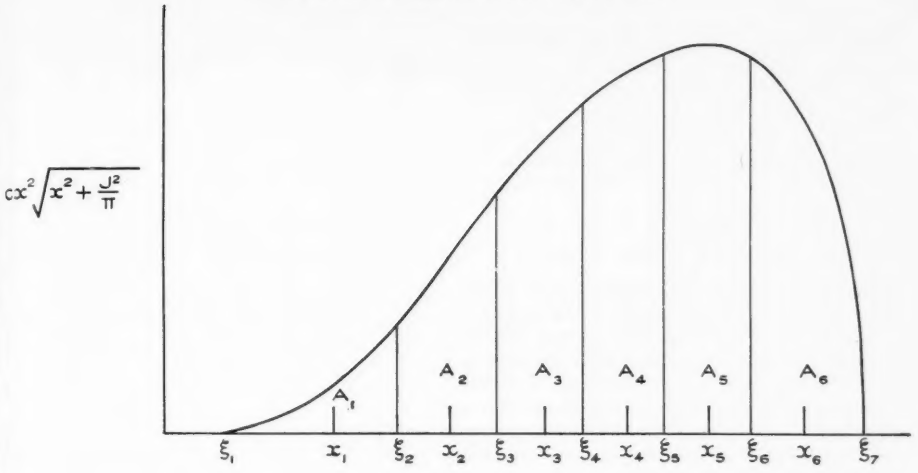

Fig. 3.

From equations (9) and (10) we get

$$\Delta\theta = \frac{\delta\alpha_1 \int_{\xi_1}^{\xi_2} Cx^2 (x^2+J^2/\pi^2)^{\frac{1}{2}}\, dx + \delta\alpha_2 \int_{\xi_2}^{\xi_3} Cx^2 (x^2+J^2/\pi^2)^{\frac{1}{2}}\, dx + \cdots}{\int_0^1 Cx^2 (x^2+J^2/\pi^2)^{\frac{1}{2}}\, dx} \quad . \quad . \quad (11)$$

When the errors $\delta\alpha_1$, $\delta\alpha_2$, $\delta\alpha_3$, and so on, are known at a number of given radii the evaluation of $\Delta\theta$ is most conveniently carried out by plotting the curve $Cx^2\sqrt{x^2+J^2/\pi^2}$ against x, determining the area enclosed by the curve and the x axis, then subdividing this area into segmental areas corresponding to the stations x_1, x_2, x_3 at which the errors are measured.

For example, suppose there are six stations x_1, x_2 - - x_6 and that ξ_1, ξ_2 - - - ξ_7 define the boundaries of the segments in which the errors are measured (Fig. 3). Denoting by A_0 the total area under the curve and by A_1, A_2, - - - A_6 the segmented areas, equation (11) is then equivalent to:—

$$\Delta\theta = \frac{1}{A_0}\,(A_1\delta\alpha_1 + A_2\delta\alpha_2 + \text{- - -} + A_6\delta\alpha_6)$$

The various errors are thus "weighted" by factors proportional to the segmental areas A_1, and so on.

So far the checking stations and the segment boundaries have arbitrary positions and do not necessarily represent the best division of the blade. For any given checking station the weight factor will clearly depend upon the position of the adjacent boundary ordinates and can thus vary within fairly wide limits. Thus checking stations which are heavily weighted will carry an undue responsibility.

The degree of variation of the weight factor obtainable by an arbitrary choice of section radii is given in the following table calculated for an actual blade.

Section radius	.333	.500	.667	.833	.917	.958
Weight factor	.038	.120	.271	.299	.155	.118

The variation of the weight factor in this case is considerable and in view of the fact that the angular errors of the several stations are capable of determination with uniform accuracy, such a variation is undesirable. Further, the final result will be influenced by any errors of observation and one of given magnitude will be of greater effect if it occurs at radius .833 than at any other station. This disadvantage can be obviated by choosing a system of stations which carry equal weight factors. A method of achieving this result will be clear from the following description

which, however, for reasons not immediately relevant, envisages a system in which the inboard segment has only one half the weight factor of the remaining segments.

With six stations, a number found satisfactory for dealing with normal blades, the required weighting factors then become

$$A_1 = 1A_0/11$$

$$A_2 = A_3 = A_4 = A_5 = A_6 = 2A_0/11$$

These values of the weighting factors fix the boundaries of the segmental lengths into which the blade is to be divided with a view to making a single measurement of angular error in each segment. It remains to locate the most suitable positions of the checking stations. With a large number of segments it could be assumed that the error is substantially constant throughout each segment and then the actual gauging position would be immaterial. But in the practical case where the number of gauging stations is limited to six, for example, the error may be subject to appreciable change with the segments. It can be shown that in this case the optimum result is achieved by locating the gauging points at the radii of the centroids of the segmental areas of the weighting curve.

Thus consider the contribution to unbalance by the blade segment between radii ξ_1 and ξ_2. Whatever the law of variation of error over the length of the blade, it can be assumed that over a relatively short length it is linear. Let the error between the boundaries be given by $E = E_1 + S(x - \xi_1)$ represented by the line $A\,B$ in Fig. 4. Where E_1 is the error at $x = \xi_1$, and S is the unknown slope of the error curve. Also let y denote the ordinate of the weighting curve at radius x. Then the correct weighted error for the blade segment is given by

$$E_w = \int_{\xi_1}^{\xi_2} E y dx = \int_{\xi_1}^{\xi_2} \{ E_1 + S(x - \xi_1) \}\, y dx$$

$$= (E_1 - S\xi_1) \int_{\xi_1}^{\xi_2} y dx + \int_{\xi_1}^{\xi_2} S x y dx$$

but,

$$\int_{\xi_1}^{\xi_2} S x y dx = S\bar{x} \int_{\xi_1}^{\xi_2} y dx$$

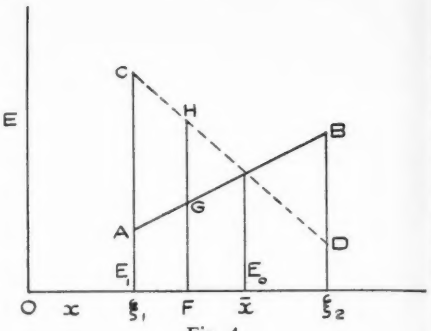

Fig. 4.

Where $\bar{x}$ is the radius of the centroid of the weighting curve segmental area. Hence

$$E_w = \{ E_1 + S(\bar{x} - \xi_1) \} \int_{\xi_1}^{\xi_2} y dx = E_0 A_1$$

Where E_0 is the actual error at radius $\bar{x}$ and A_1 is the area under the weighting curve between ordinates ξ_1 and ξ_2. It is important to note that the complete weighted error for the segment is given by the product of the error measured at $\bar{x}$ and the area of the weighting curve segment, and that the result is quite independent of the slope of the error curve. For example, the result would not be affected in any way if the error varied according to the dotted line $C\,D$ in Fig. 4.

Thus compare corresponding segments of two blades over which range the integrated weighted errors have the same value, but the slopes of the local error curves differ. Let $A\,B$ represent the error variation for the first blade and $C\,D$ that of the second blade and suppose the radius of the gauging point to be arbitrarily chosen as $O\,F$. The observed errors will then be $F\,G$ and $F\,H$ respectively and the apparent weighted errors will differ by an amount proportional to $G\,H$, whereas the true weighted error is common to both blades and is proportional to the common ordinate E_0 at radius $\bar{x}$.

The same principle applies to any blade segment, consequently the interesting conclusion is reached that whatever the law of variation of error, the total weighted error for the blade can be obtained by gauging the blade at a limited number of points, provided that they are located at the centroids of the segments of the weighting curve.

The stations at which the angular errors are to be determined have the unique radii $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$, and so on, and, in general, these will not coincide with the standard stations specified for manufacturing purposes.

Thus the following advantages are secured by choosing the stations in the prescribed manner: —

(1) The observation stations being of substantially equal importance, errors of observation will tend to cancel out, whereas, if the usual drawing stations are employed, the weights become very unequal and put an undue responsibility on one or two measurements.

(2) By adopting stations which are not specified in the manufacturer's drawing and in consequence are not subject to close inspection or control, there is greater probability of discovering aerodynamic discrepancies than would otherwise be the case.

A method for obtaining thrust moment balance having been described, it remains to examine the procedure for torque force balance. Comparing the two basic equations (7) and (8) it is seen that for torque balance we must use the function $C\,(x^2 + J^2 / \pi^2)^{\frac{1}{2}}$ instead of $Cx^2\,(x^2 + J^2 / \pi^2)^{\frac{1}{2}}$ Thus the weighting curve for torque balance is given by $y = C\,(x^2 + J^2/\pi^2)^{\frac{1}{2}}$. Otherwise the calculation proceeds exactly as for the thrust case, step for step.

The errors referred to in the preceding analysis are the angular differences between some fixed datum plane and the zero lift lines of the actual and the corresponding idealised blades. It is thus necessary to determine the zero lift line and devise means for locating it. A convenient determination is the approximate one given by Munk in N.A.C.A. Technical Note No. 122, according to which the direction of the zero lift line of an aerofoil section is defined by the straight line joining the centre of curvature of the trailing edge and the point at the mean height of the ordinate at 50 per cent. of the chord, as in Fig. 5.

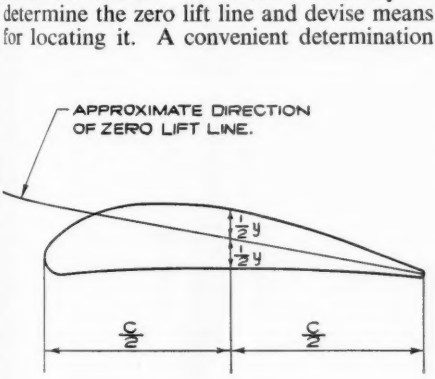

Fig. 5.

This definition of the zero lift line is a close approximation to the true direction and is sufficiently accurate for the present purpose. In fact, whatever discrepancy may be introduced by its application to a particular blade section is virtually cancelled in the final result, by adopting the same approximation for both the actual and corresponding idealised blades.

The direction of the zero lift line is controlled by the angle between the reference plane, *e.g.* the plane of rotation, and the pressure face of the section and also by the thickness of the section, both of which quantities are subject to manufacturing errors. A convenient gauge devised by the writer to locate the zero lift line as defined above is shown in Fig. 6. This instrument has two bell crank legs hinged about a common pivot and connected by links to a spring-loaded block arranged to slide on a centrally disposed splined rod. The lower end of the rod terminates in a V-notch which engages the trailing edge of the blade. The whole is arranged so that the axis of the rod and the V-notch lie in the plane of symmetry which bisects the angle between the two legs. A pair of contact points on the legs can be adjusted to any desired position and locked therein. The upper end of the splined rod carries a small platform, the upper surface of which is perpendicular to the plane of symmetry of the legs. Fig. 6 shows the instrument embracing a blade section with the contact points adjusted to contact the section at mid chord, and a gravity controlled clinometer resting on the platform. Direct reading of the clinometer then gives the angle between the zero lift line and the vertical plane.

With the equipment just described, caliper gauge and clinometer, it is possible to ascertain the overall correction angle for any blade by comparing a number of its sections with those of a master blade, which for convenience can be the theoretical blade represented by the blade drawing devoid of manufacturing tolerances. If all the blades of a series are thus calibrated against the

same master blade, manifestly they will be rendered aerodynamically interchangeable.

In the early days of the war several hundred propellers were treated in this manner but the process was tedious and time consuming. In addition, it required skilled operatives to set up the blades and make the routine calculations for each calibration, consequently some speedier method was sought which could dispense with skilled operatives and, if possible, eliminate the labour of computation.

The final outcome was an apparatus which gave a considerable increase in the output of calibrated blades, entirely eliminated all calculation and used only unskilled labour. This apparatus displays the overall aerodynamic correction for a propeller blade by indicating on a graduated scale the integrated result of a number of separate comparisons; for this reason it became known as a blade integrating machine.

The complete integrating machine is illustrated in Fig. 7 which shows all the essential components, the most prominent of which are the table (1) supporting a blade in the calibrating position and the target frame (18) in the background. These are arranged parallel to one other so that the centre line of the table is separated by 100 inches from the front of the target frame.

The table carries a superstructure which supports six blade caliper gauges each similar to that already described but with the clinometer replaced by an optical projector having its optic axis perpendicular to the gauge axis. Each projector throws an image of an illuminated cross on to a corresponding adjustable plaque (12) carried by the target frame. Each plaque is engraved with a horizontal fiducial line and can be raised or lowered on its vertical guide (19) by means of a hand wheel (13) geared to a screw co-operating with a nut attached to the plaque. A vertical displacement of any plaque is transmitted over a system of pulleys by means of a thin bronze tape to the pointer (14) of the scale (15) shown on the left of Fig. 7. This pulley arrangement can be seen in Fig. 8 which shows the back of the target frame.

Each gauge, together with its attached optical projector, is supported from the table superstructure by a lever and link, in such a manner as to have complete freedom in a vertical plane so that when the gauge is presented to the blade it readily assumes the zero lift direction, as shown in Fig. 9.

The gauges are constrained by suitable collars on the hinge bar (20) to move only in the vertical planes defined by the radii of the gauging stations determined by the method previously described.

With the gauges appropriately spaced according to the design of blade to be calibrated, it is necessary to set the fiducial lines of the plaques at the correct heights above the centre line of the blade before the latter is placed in the headstock. These distances, referred to as target heights for brevity, are calculated from the nominal dimensions given by the blade drawing, omitting tolerances. They therefore relate to the ideal blade. In order to avoid the effects of inaccuracies in the gauges and projectors, certain precautions are taken in transferring the heights to the target screen. Possible inaccuracies in these components are asymmetry of the gauge and misalignment of the optic axis, the combined error of which can be appreciable and which itself is subject to the inherent magnification of the system.

Without striving for extreme precision in the instruments, any difficulty arising from

Fig. 6.

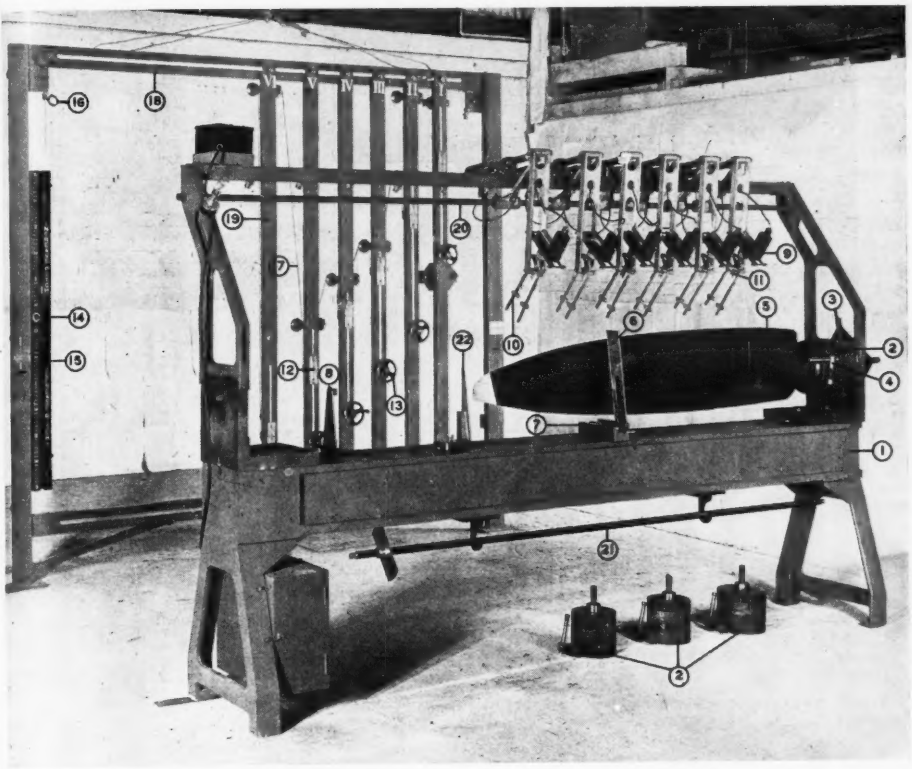

Fig. 7.
Rotol Aerodynamic Balancing Machine.

1. Blade table.
2. Split headstock.
3. Large Capstan to prevent rotation of headstock.
4. Small Capstan to lock headstock.
5. Propeller Blade.
6. .7 Station setting gauge.
7. Adjustable base for setting gauge.
8. Steady for graduated rod.
9. Projector.
10. Rollers on gauge legs.
11. V-notch to register on trailing edge of section.
12. Adjustable plaque.
13. Hand wheel controlling adjustment of plaque.
14. Scale pointer.
15. Scale.
16. Tape adjusting nut.
17. Bronze tape.
18. Target frame.
19. Vertical guides.
20. Horizontal hinge bar.
21. Graduated Rod.
22. Target datum wedge.

imperfection can be resolved by the aid of the target datum wedge (22). This is designed so that if a perfect optical gauge could be applied to it, as in Fig. 10, the light beam would be focused on the target screen precisely on the same level as the blade axis and thus provide a datum from which the theoretical target height could be measured. The light image from any actual gauge, however, will be either above or below the true position. Suppose it falls two inches below, then taking this false position as a datum, when the corresponding plaque is adjusted to the theoretical height above the datum the result will be that the fiducial line, or target, is also two inches below its true position. Each target is similarly adjusted, using the appropriate target height and the corresponding gauge on the datum wedge. When all the targets have been positioned

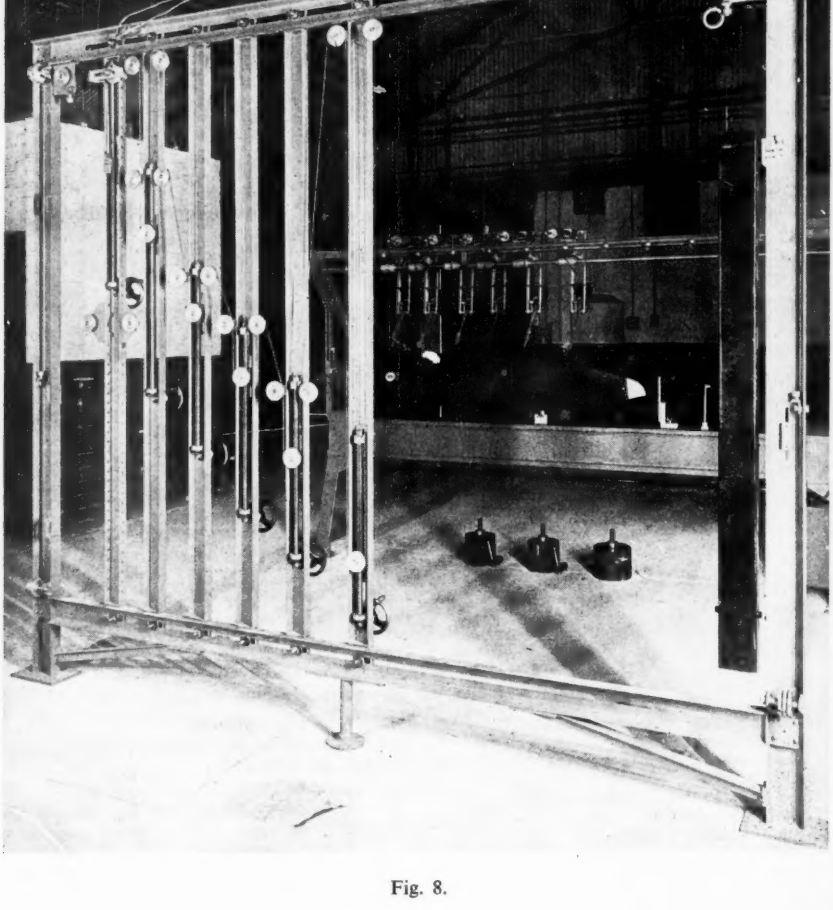

Fig. 8.

thus, the pointer is set opposite the zero of the scale by lengthening or shortening the bronze tape to suit.

For calibration the blade is held in a headstock (2), trailing edge uppermost, and locked in position with its characteristic section (generally that at 0.7 *R*) set at a convenient angle to the vertical with the aid of the setting template (6) applied to the pressure face of the blade.

Imagine a perfect blade to be set up in this manner and the gauges in turn offered to the blade as in Fig. 11. Despite the unavoidable inaccuracies of the gauges, the light images will then coincide with their corresponding targets by virtue of the fact that the latter were primarily displaced from their true position by the exact amount required to annul the instrument errors.

On repeating the process with an actual blade it is generally found that some or all of the images do not fall on the targets, being either above or below them. In this case the calibration is completed by rotating the

handwheels (13) until the targets coincide with the light images. Each adjustment of a target causes a corresponding displacement of the scale pointer and, when all six targets have been adjusted, the pointer indicates the angular correction which must be finally applied to the blade to obtain aerodynamic balance.

Reference to Fig. 7 will show the targets numbered I to VI and a left hand tractor blade installed ready for calibration; it will also be clear that the elements of the machine can be transposed for calibrating a blade of the opposite hand. In either case number I target always deals with the inboard section of the blade. This target differs from the others in one important respect. The end of the bronze tape is attached directly to No. I target, whereas each of the others is provided with a pulley over which the tape runs. The scale pointer is also provided with a pulley with the result that a two inch traverse of No. I target displaces the pointer by only one inch. In all the other cases a given displacement of the target causes an equal displacement of the pointer.

This odd arrangement has a beneficial effect in giving a more uniform distribution of the gauges than would otherwise be the case. It arises from an examination of the shape of the weighting curve (*c.f* Fig. 3) which, because of the small ordinates at the inboard end of the blade, would require a correspondingly large segmental blade length if a common weighting factor were to be used and so cause crowding of the outboard gauges. This difficulty has been avoided by making the weighting factor for the inner gauge only one half that of the remaining gauges.

Of the possible methods of weighting the blade errors according to their importance, *e.g.* modulation of the target displacements, by levers or cams, during transmission to the scale pointer, the quasi-equal weighting system embodied in the integrating machine is by far the simplest, as the machine can accommodate any type of blade without modification to the weighting system, and it gives a close approximation to the mathematically correct integration by reducing the problem to one of simple addition or subtraction.

The integrating machine illustrated in Fig. 7 is a war-time product and was made as simple as possible consistent with functional requirements. With the exception of the special gauges and optical projectors, it employed only readily available material. Nevertheless, it proved extremely satisfactory in service. It contains, however, one or two refinements which are of interest if not essential. The first concerns the lamps of the projectors. Since these have to be enclosed they are prone to overheating if left glowing continuously, although they are only 12 volt 36 watt ordinary motor bulbs. This difficulty was met by providing simple mercury switches attached to the arms supporting the gauges, which switch off each lamp as the gauge is raised and only allow the lamp to glow when the gauge is lowered to the operative position.

A second feature, discernible in Fig. 8, is the provision of a temperature compensation device. When the machine was designed it

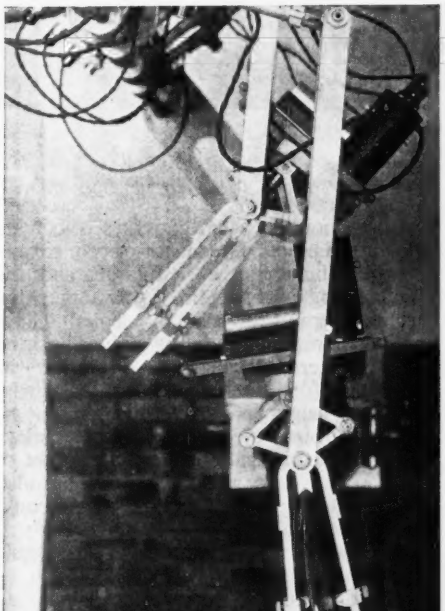

Fig. 9.

Fig. 10.

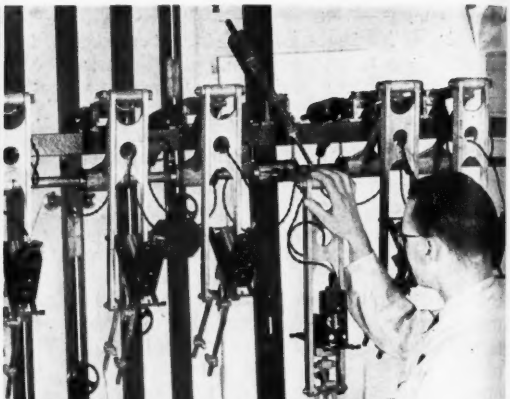

Fig. 11.

was not known in what extremes of climate it might be used. The length of bronze tape contained between the first target and the pointer being considerable, it was anticipated that temperature variations could cause corresponding changes in the pointer position and so give erroneous results. Provision was made, therefore, to suspend the scale from a similar length of tape which could be wrapped around the system of idler pulleys shown in the vertical channel at the right of Fig. 8. The scale and the pointer are also equally loaded. Hence thermal effects could be completely eliminated. In practice it was found that, in Great Britain at least, this device is unnecessary, consequently it is shown disconnected in the accompanying photographs.

Before leaving this description of the integrating machine it is worth noting that once the machine has been set for blade calibration, the targets do not need resetting after subsequent calibration. They can be left in their disturbed positions, when calibrating any number of blades of the same type, without adversely affecting the results. Where there is only one propeller concerned, such as a prototype, and interchangeability is not involved, it is sufficient to balance the component blades between themselves. In this event it is unnecessary to calculate the target heights, but the spacing of the gauges must be determined as in the more general case. Any blade of the set may be chosen as master and set up in the headstock for calibration. The gauges are then applied one by one and the targets brought into coincidence with the light images. Having done this the pointer is set to zero and the master is regarded as requiring no correction. The remaining blades are then calibrated in the usual manner. This process ensures that the complete propeller will be aerodynamically balanced for either thrust or torque, as the case may be, when the indicated corrections to the normal blade angles have been made.

The information supplied by the integrating machine can be applied in several ways, depending upon the availability of dynamic particulars of the airframe and whether the blades are treated as individuals or grouped into propeller sets.

In the absence of any information regarding the nodal position in the airframe, the

best that can be done is to adopt either pure thrust, or pure torque balance, by suitably biasing the blade angles on assembly in the hub. In either case there will be a residue of the second type of unbalance which may or may not be important. On the other hand, if the nodal position of the airframe together with certain aerodynamic characteristics of the blades are known, two courses are open. Taking the first one, the individual thrust and torque corrections can be compounded so that when the blades are chosen at random for assembly in a hub, and each blade is adjusted according to its own composite correction, the optimum overall balance will be obtained. The second course requires a knowledge of the distribution of the calibrated errors after building the propeller. With this information it is possible to make a final adjustment to two of the blade angles in order to eliminate any residual unbalance and thus completely balance the propeller for both thrust and torque, relative to the airframe node.

Consider the moments about the node produced by the excess or "unbalanced" thrust and torque forces due to the imperfections of a single blade. Let α, β be the integrated angular thrust moment and torque force errors respectively (the normal correction angles would then be $-\alpha, -\beta$) also let l denote the distance between the node and propeller disc (Fig. 12).

The unbalanced thrust moment will be $k_1\alpha$ and the unbalanced torque force will have a moment $lk_2\beta$ about the node where k_1, k_2 are constants dependent on the blade design and operating conditions. The total moment of these two components about N is,

$$M=(k_1^2\alpha^2+l^2k_2^2\beta_2)^{\frac{1}{2}}.$$

Twisting the blade through an angle γ will change this moment to M_1 where

$$M_1=\{\,k_1^2(\alpha+\gamma)^2+l^2k_2^2(\beta+\gamma)^2\,\}$$

If M_1 could be reduced to zero for each blade by a suitable choice of γ the propeller would be in balance but unless $\alpha=\beta$ there is no real value of γ which would have the desired effect. However, by differentiating M_1 with regard to γ it is found that M_1 is a minimum when

$$\gamma=-(\alpha+K^2\beta)/(1+K^2)$$

where $K=lk_2/k_1$ and the minimum value of M_1 is then given by

$$M_{\min}=\frac{k_1K}{\sqrt{1+K^2}}(\alpha-\beta)$$

When the blades of a propeller are chosen at random, each blade adjusted by the angle

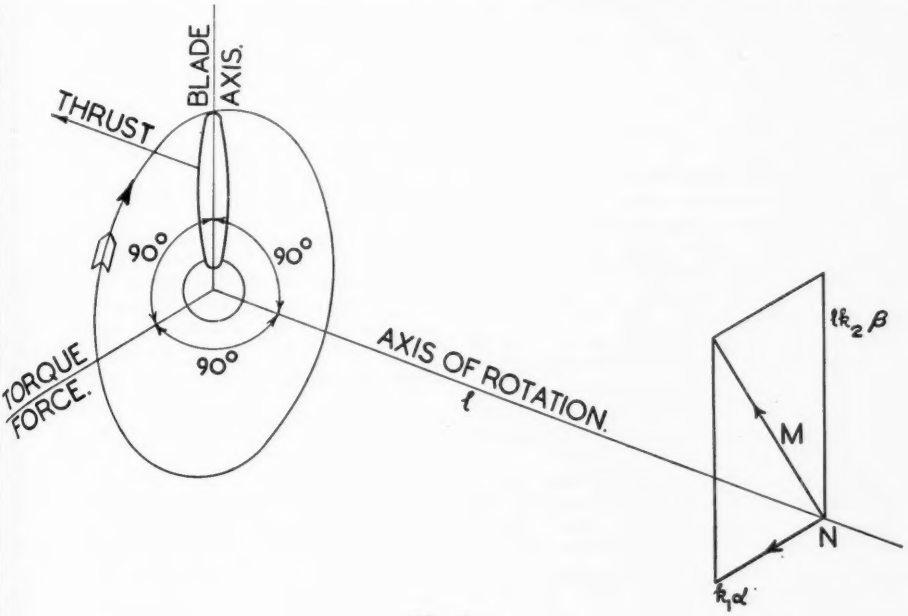

Fig. 12.

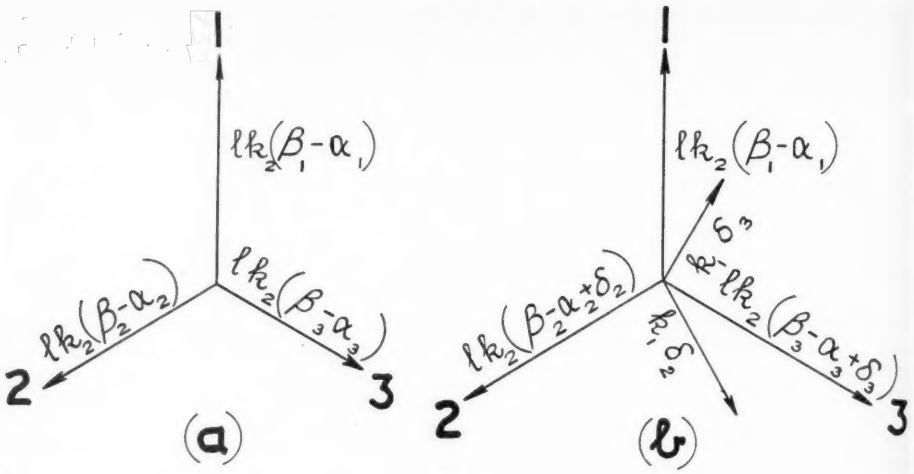

Fig. 13.

γ will have the least potential unbalance, but it should not be overlooked that the balance of the completed propeller could conceivably be improved by interchanging the blades in the hub. Indeed, some optimum arrangement of blades is generally possible. Alternatively, if the component blades of a propeller could be selected so that the magnitude and sign of $(\alpha - \beta)$ were common throughout the propeller, the resulting aerodynamic balance would be complete.

Where a single propeller is concerned, a more direct and less complicated approach is to first determine the overall thrust and torque errors for each blade as before and, after assigning the blade positions in the hub, to apply the corrections required for thrust balance. This will leave only torque unbalance and the corresponding vectors in the nodal plane will be parallel to the respective blade axes. The problem then resolves itself into finding what angular adjustments will nullify the residual torque unbalance.

For example, consider a three-bladed propeller in which the individual thrust and torque errors are α_1, β_1, and so on.

After correcting for thrust the torque unbalance vectors will be as shown in Fig. 13(*a*). If now the angles of Nos. 2 and 3 blades receive increments δ_2 and δ_3 respectively, their torque components will be modified and components of thrust unbalance will be introduced, as in Fig. 13(*b*). Resolving these vectors vertically and horizontally and equating to zero which is the condition required for balance, we get

$$\delta_2(K+\sqrt{3})+\delta_3(K-\sqrt{3})+$$
$$+K(\beta_2+\beta_3-\alpha_2-\alpha_3)-2K(\beta_1-\alpha_1)=0$$
$$\delta_2(1-\sqrt{3K})+\delta_3(1+\sqrt{3K})-$$
$$-\sqrt{3K}(\beta_2-\beta_3-\alpha_2+\alpha_3)=0$$

from which

$$\delta_2=\frac{K}{\sqrt{3}(1+K^2)}\{(\sqrt{3K}+1)(\beta_1-\alpha_1)-$$
$$-(\sqrt{3K}-1)(\beta_2-\alpha_2)-2(\beta_3-\alpha_3)\}$$
$$\delta_3=\frac{K}{\sqrt{3}(1+K^2)}\{(\sqrt{3K}-1)(\beta_1-\alpha_1)+$$
$$+2(\beta_2-\alpha_2)-(\sqrt{3K}+1)(\beta_3-\alpha_3)\}$$

Hence, adjusting Nos. 2 and 3 blades by δ_2 and δ_3 results in a redistribution of thrust and torque errors which have zero moment about the node. These, together with the total correction angles for complete balance, are given in the following table.

Blade No.	1	2	3
Net thrust error	0	δ_2	δ_3
Net torque error	$\beta_1-\alpha_1$	$\beta_2-\alpha_2+\delta_2$	$\beta_3-\alpha_3+\delta_3$
Correction angle for complete balance	$-\alpha_1$	$-\alpha_2+\delta_2$	$-\alpha_3+\delta_3$

COEFFICIENTS OF FRICTION

by

E. C. PIKE, M.A., A.F.R.Ae.S.

SUMMARY

A summary is presented of information collected on coefficients of friction (rolling and sliding) between rubber tyres and road or runway surfaces. Nearly all the data collected are from tests on automobile tyres and are limited to speeds of about 40 m.p.h. In some cases the primary object of the tests was to distinguish between good and bad roads, and not to determine absolute values of friction coefficients.

The reasons for the importance of the information for aircraft design use are discussed and distinctions are made between coefficients measured in different ways.

The results show the variation of sliding friction coefficient with various parameters at speeds up to 40 m.p.h. There is a set of American tests at speeds up to 110 m.p.h., and some estimates made by the Dunlop Rubber Company up to 120 m.p.h

It is concluded that for sliding friction coeficients differences in surface texture (as distinct from surface material) are significant, and that information can be given only in the form of limits within which the values can be expected to lie.

Few results are available on the variation of rolling resistance coefficient, but it is felt that the approximate values quoted for different types of surface are sufficiently accurate.

NOTATION

$B.F.C.$ = braking force coefficient = $\frac{\text{braking force}}{\text{load}}$, *i.e.* coefficient of friction when skidding forwards (see Section 2).

N = percentage slip, *i.e.* ratio (speed of point of contact of wheel)/(forward speed of vehicle). (Zero slip represents free rotation, and 100 per cent. slip a locked wheel).

$R.R.C.$ = μ = rolling resistance coefficient = frictional force during pure rolling/load.

$S.F.C.$ = sideway force coefficient = $\frac{\text{sideway force}}{\text{load}}$ (see Section 2).

Sideway force = the force acting at right angles to the plane of a wheel while it is being dragged forward rotating, with its plane of rotation vertical and at an angle θ to the direction of motion (see Section 2).

s_1 = length of ground run during take-off.

T_M = mean effective thrust of aircraft during take-off.

W = weight of aircraft.

θ = angle of inclination of wheel to direction of motion (see "sideway force").

μ = (see *R.R.C.*).

$\Delta\mu$ = error in μ.

1. INTRODUCTION

The present paper is a summary of information on coefficients of friction between tyres and road or runway surfaces. It was prepared on behalf of the Royal Aeronautical Society's Performance Sub-Committee after visits to the Road Research Laboratory, the Dunlop Rubber Company

Paper received September 1949.

Miss Pike is a member of the Technical Staff of The Royal Aeronautical Society.

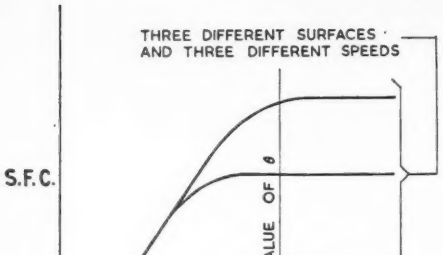

Fig. 1.
Variation of *S.F.C.* with angle of inclination of wheel to direction of motion (curves from Ref. 1).

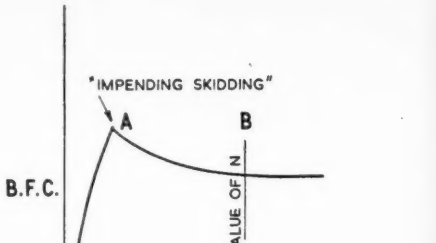

Fig. 2.
An example of variation of *B.F.C.* with percentage slip (curve from Ref. 1).

and the Royal Aircraft Establishment and after reference to the literature available. The purpose of the investigation was to determine whether the information could be presented usefully in data sheet form.

The information is necessary in the estimation of take-off, landing and accelerate-stop distances. The coefficient of rolling resistance (*R.R.C.* or μ) affects the take-off run and the value of the braking force coefficient (*B.F.C.*) determines at what point in the landing run it is safe to apply full brakes without the danger of skidding. The *B.F.C.* can also be used to determine the direction of the resultant force on the undercarriage at the instant of touch-down.

There appear to be two schools of thought about the necessity of precise information on the value of *B.F.C.* Theoretically, if *B.F.C.* is plotted against forward speed, the speed

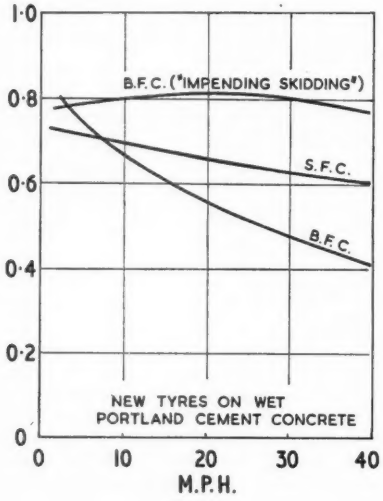

Fig. 3.
Difference between *B.F.C.* and *S.F.C.* (Ref. 2).

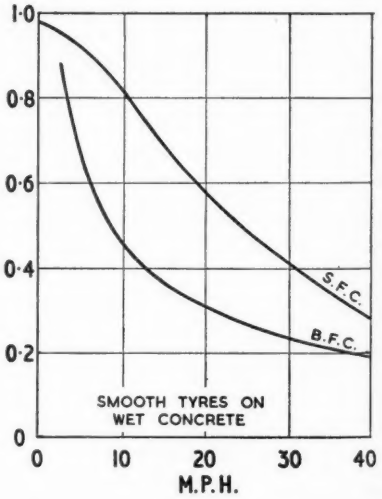

Fig. 4.
Difference between *B.F.C.* and *S.F.C.* (Ref. 3).

at which the *B.F.C.* is equal to the brake torque coefficient is the maximum speed at which full brakes can be applied safely. With the heavily loaded aircraft of the future it is becoming increasingly important to be able to apply full brakes as soon as possible, and so it is necessary for designers to have precise knowledge of the value of *B.F.C.* On the other hand it can be argued that even if a close value could be obtained it would be dangerous to design to it. Any slight variation of load due to a bump on the runway would result in skidding of a wheel and possibly serious damage to the tyre. The same conditions might result from the aircraft's encountering a dry or rough spot on the runway, or a puddle. Adherents to this second school of thought maintain that the application of the brakes will always be a matter of pilot's judgment and that tests aimed at determining precise values of *B.F.C.* are not worthwhile.

2. DISTINCTION BETWEEN *B.F.C.* AND *S.F.C.*

It will be seen from the results that, apart from the rolling resistance coefficient, three types of "skidding coefficient" can be measured, and it is important to distinguish between them.

In this country and in France, most of the measurements are of sideway force coefficient (*S.F.C.*). A wheel with its plane of rotation vertical, but set at an angle θ to the direction of motion, is dragged forward rotating. The ratio of the force acting at right angles to the wheel to the load on the wheel is the *S.F.C.* It will be seen from Fig. 1 that the *S.F.C.* is practically constant with variation in θ under all conditions for values of θ greater than about 20° (the "critical angle"). All references to *S.F.C.* agree at least on this point.

Most of the American tests are of braking force coefficient (*B.F.C.*). This is the ratio of the braking force to the load on the wheel, *i.e.* the coefficient of friction when skidding straight ahead. Fig. 2 shows how this varies with percentage slip, *i.e.* the ratio (speed of point of wheel in contact with the ground relative to the ground) in a typical case. The peak value (*A*) is called by the Americans the "impending skidding coefficient" and it is interesting to note that about 90 per cent. of this maximum value can be achieved with less than 10 per cent. slip. It has been argued that the "impending skidding coefficient" is the value which is of interest since it occurs first, but the fallacy in this argument is that it is impossible to ensure that all wheels slip the same amount at the same time. There is no doubt that the *B.F.C.* under full sliding conditions (*i.e.* in the region beyond *B* in Fig. 2) is the value which is required.

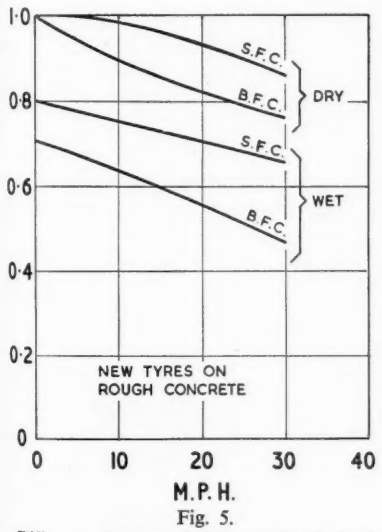

Fig. 5.
Difference between *B.F.C.* and *S.F.C.* (Ref. 2).

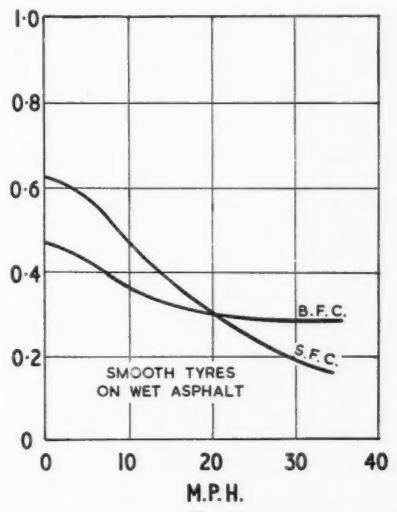

Fig. 6.
Difference between *B.F.C.* and *S.F.C.* (Ref. 1).

References 5 and 10 claim that beyond the critical values of θ and N, *B.F.C.* and *S.F.C.* are substantially the same. Some examples of the differences between them are shown in Figs. 3, 4, 5 and 6, but in view of the difficulty of accurate measurement, the assumption seems reasonable.

3. METHODS OF MEASUREMENT

It has been mentioned earlier that most of the British and French results are of *S.F.C.* The main reason for this is that tyre wear is much less than when *B.F.C.* is measured; another reason is that the power required to drive the vehicle is less, and a third reason is that on wet surfaces, piling up of liquid in front of the tyre is avoided. The Road Research Laboratory use a sidecar wheel inclined at 20°[1], and for the French tests[3] a trailer with two equally inclined wheels was used.

B.F.C. can be measured directly by means of dynamometers, or by recording the deceleration. A third method is to measure the stopping distance of the vehicle, but in this case only the mean deceleration over the speed range is obtained. Very often in measurements of *B.F.C.* the same part of the tyre is always in contact with the road surface, and becomes smooth during recording of the results.

The aim of most of the tests made so far has been primarily to distinguish between good roads and bad, from the motorists' viewpoint, and for this purpose measurements of, for example, *S.F.C.* are a good indication.

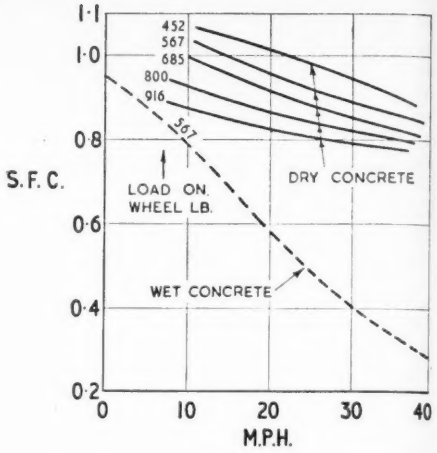

Fig. 7.
Effect of speed (from Ref. 3, "Stradographe" method).

4. RESULTS

With two exceptions (Figs. 16 and 17) the results given in Tables I to III and Figs. 3

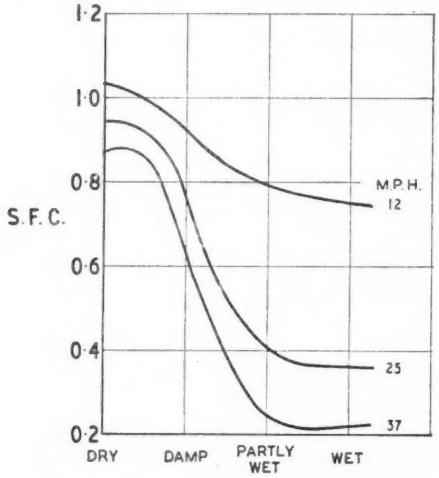

Fig. 8.
Effect of "wetness" (concrete) (from Ref. 3, "Stradographe" method).

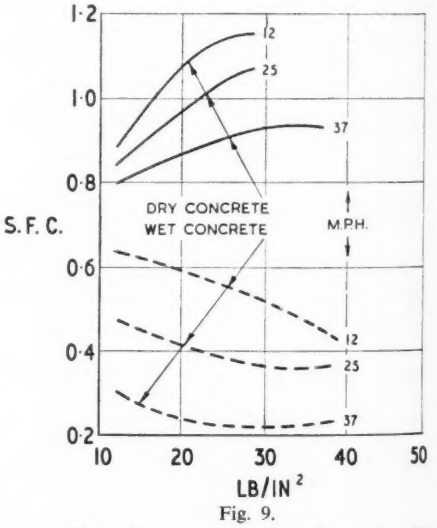

Fig. 9.
Effect of tyre pressure, dry and wet concrete (from Ref. 3, "Stradographe" method).

to 17 refer to automobile tyres and are limited to about 40 m.p.h. One of the most useful papers is Ref. 3, which summarises all the information available in 1936 from Great Britain, U.S.A., France, Holland, Sweden, Italy and Germany and in addition gives details of the comprehensive tests organised by the S.F.E.R.B. (le Syndicat des Fabricants d' Emulsion Routières de Bitume) at about this time.

4.1. *B.F.C.* AND *S.F.C.* AT SPEEDS UP TO 40 M.P.H.

Figures 7, 8 and 9 show the effects of various parameters on *S.F.C.*, from Ref. 3.

4.1.1. *Effect of speed*

The effect of speed is not nearly so marked on dry surfaces as on wet. This is because on wet surfaces a film of water has to be displaced before true contact between the surfaces is achieved, and the greater the speed the less time there is for the film to be dispersed.

The effect of speed is shown in many of the figures, particularly Figs. 7 and 8. All sources of information agree that tests at, for example, 5 m.p.h., give no indication of values at higher speeds.

4.1.2. *Effect of different types of surface*

The type of surface is more significant than the type of tyre and particularly, the surface texture is more important than the actual materials of which the road or runway is composed (Figs. 10, 11 and 12).

The difference between results on wet concrete in Great Britain and in France, under similar conditions, is particularly striking and is shown in Fig. 14.

TABLE I

Tests by Goodrich Company on wet brick pavement with balloon tyres of different treads.

	B.F.C. Static (before slipping)		*B.F.C. Sliding* (after slipping)	
Speed: m.p.h.	5	30	5	30
Smooth tyre	0.49	0.28	0.43	0.26
Circumferential grooves	0.58	0.42	0.52	0.36
Angular grooves at 60°	0.75	0.55	0.70	0.39
Angular grooves at 45°	0.77	0.55	0.68	0.44

TABLE II

B.F.C. abstracted from the curves of Ref. 5. (Values for *S.F.C.* given in this reference are very similar.)

Concrete	— 0.55-0.70 at any speed, wet or dry.
Smooth asphalt	— dry, 0.6-0.75, constant with speed.
	— wet, 0.70 at 0 m.p.h. falling to 0.2-0.4 at 30 m.p.h.
Wood paving	— dry, 0.5-0.7, more or less constant with speed.
	— wet, 0.3-0.6 at 0 m.p.h. down to 0.2-0.45 at 30 m.p.h.

TABLE III

Approximate values of *B.F.C.* at 30 m.p.h. on typical surfaces (from Ref. 6).

		New tyres	*Smooth tyres*
Rough tar-dressed	— dry	0.8 - 0.9	0.8 - 0.9
	— wet	0.6 - 0.8	0.5 - 0.75
Rough concrete	— dry	0.9 - 1.0	0.9 - 1.0
	— wet	0.6 - 0.7	0.5 - 0.6
Polished asphalt	— dry	0.45 - 0.55	0.45 - 0.55
	— wet	0.45 - 0.55	0.20 - 0.25
Worn wood blocks	— wet	0.2 - 0.3	0.2 - 0.3
Smooth ice	— dry	0.15	0.15
	— wet	0.10	0.10

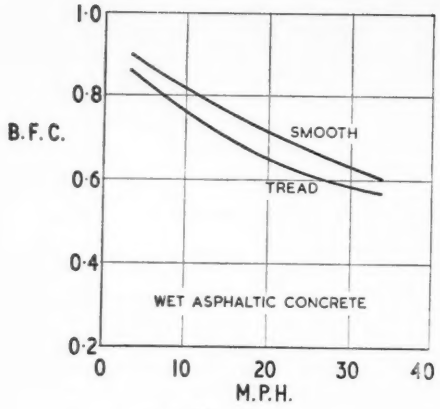

Fig. 10.
Effect of tread, wet asphaltic concrete (from Ref. 2).

4.1.3. *Effect of tread*

Some examples of the effect of tread are shown in Figs. 10, 11 and 12. The effect is noticeable only on wet surfaces, because of the squeegee action of the treaded tyre, but it is small in any case.

4.1.4. *Effect of tyre size*

Some indication of the effect of tyre size is given in Fig. 13, although the effect of a change in pressure is included as well.

4.1.5. *Effect of tyre pressure*

Figure 9 shows the effect of tyre pressure.

4.1.6. *Effect of load on wheels*

An indication of the effect of the load on the wheels is shown in Fig. 7. The tendency is corroborated by the tests at higher speeds (Fig. 16), but it is not clear whether or not the tyre pressure was constant during these latter tests.

4.1.7. *Effect of temperature*

Although few results are available on temperature effect, in general there appears to be a slight increase in coefficient with decrease in temperature[2].

4.1.8. *Effect of moisture and of ice*

The effect of the " wetness " of the surface is shown in Fig. 8. It was pointed out by the Road Research Laboratory that the coefficient for a tyre on a water film is 0.10, and that most wet surfaces tend to this value as speed increases. It is interesting to note that the Air Registration Board and International Civil Aviation Organisation landing requirements are based at present on *dry* concrete.

The coefficient for ice on pavement is 0.15 to 0.20 and is independent of speed. (The application of sand or cinders increases this to 0.2 to 0.4.)

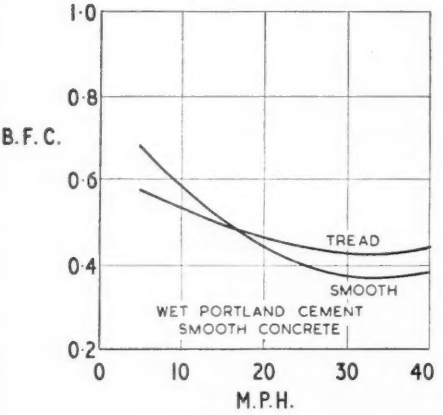

Fig. 11.
Effect of tread, wet Portland cement smooth concrete (from Ref. 2).

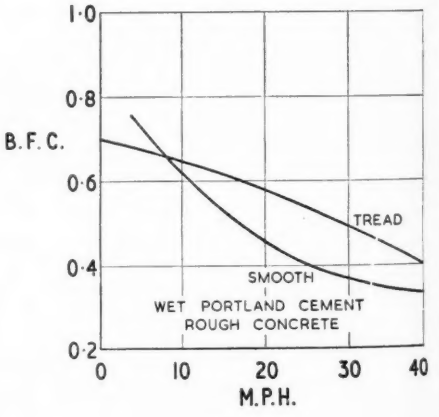

Fig. 12.
Effect of tread, wet Portland cement rough concrete (from Ref. 2).

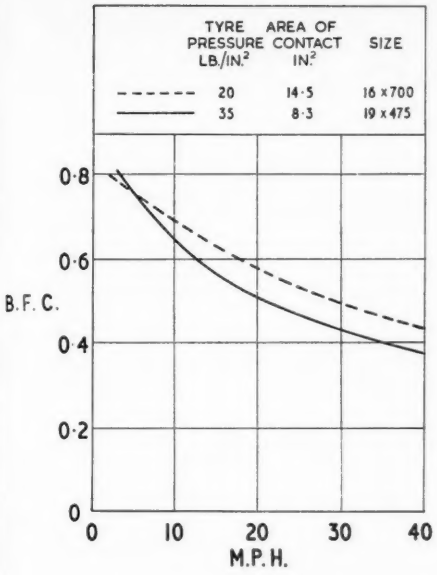

Fig. 13.
Effect of tyre size and pressure (Ref. 2).

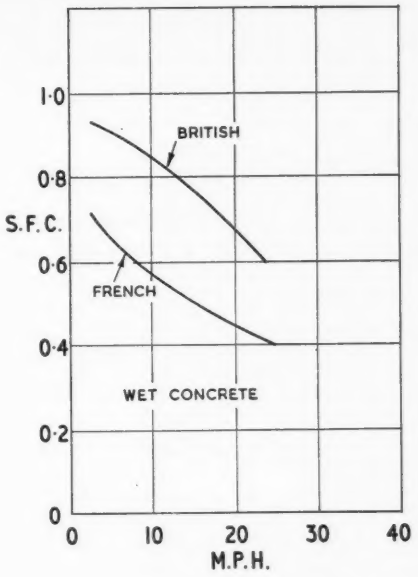

Fig. 14.
An example of differences in results (Ref. 3).

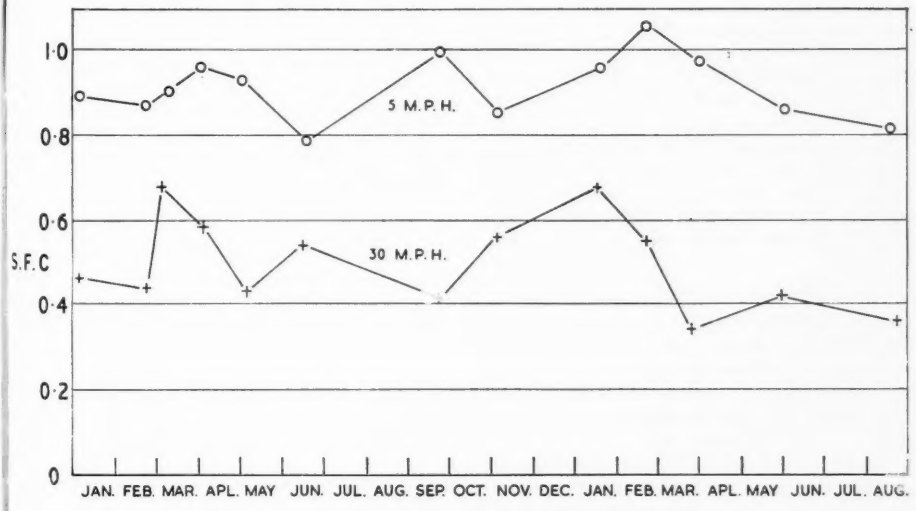

Fig. 15.
Seasonal variation—wet asphaltic concrete, painted with bitumen emulsion and spread with $\frac{3}{8}$ in. chippings, Kingston By-Pass (Ref. 1).

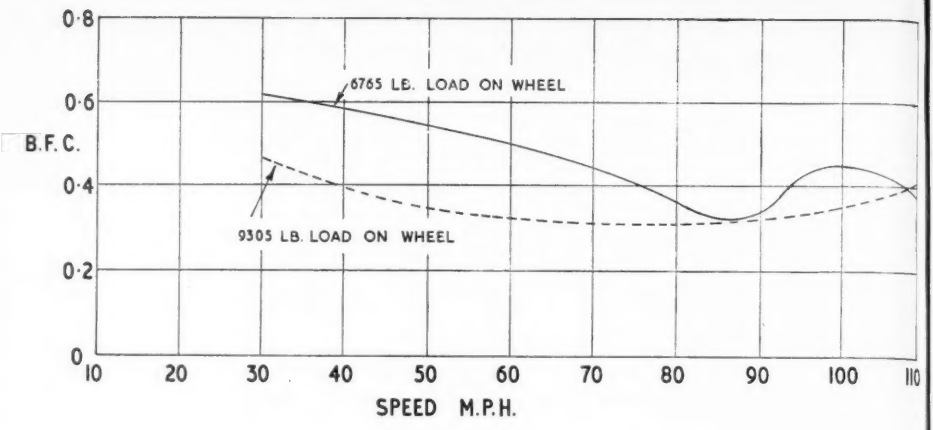

Fig. 16.
Recent U.S. Air Force tests—44 in. aircraft wheel on dry concrete.

4.1.9. *Seasonal variation*

Examples of seasonal variation on a particular stretch of road are shown in Fig. 15. French tests by Bouly, summarised in Ref. 3 showed similar variations.

4.2. *B.F.C.* AT HIGHER SPEEDS

4.2.1. *U.S. Air Force tests*

Results of recent U.S. Air Force tests on dry concrete are shown in Fig. 16. Although some of the facts are not clear from the report, for example, the tyre pressures are not quoted, the results shown are the only ones available at speeds above 40 m.p.h. The sudden change of slope at about 90 to 100 m.p.h. is thought to be due to a breakdown in the surface rubber because of a sudden local change of temperature. It is understood that further tests are being made.

4.2.2. *Dunlop estimates*

Figure 17 shows some figures provided by the Dunlop Rubber Company. The values at 30 m.p.h. are based on actual experiments on road vehicles. Those at 80 m.p.h. and 120 m.p.h. are estimates extrapolated from some limited experimental data at speeds up to 50 to 60 m.p.h. When using the values in this table the considerations already discussed in the Introduction ("second school of thought") must be clearly borne in mind. The table is presented to assist aircraft designers as a set of reasonably true values precisely because of the impractibility of safe and reliable measurement at the highest speeds.

4.3. ROLLING RESISTANCE COEFFICIENT (μ)

There appears to be little information on *R.R.C.*, apart from tables of values for different surfaces given in most text books, similar to Fig. 22. Figs. 18 and 19, which have been obtained from Ref. 4, are of some interest and show that the variation of μ with speed is not large. Fig. 20 shows the estimated effect on ground run of an error $\Delta\mu$ in the estimation of μ, for various values of (mean thrust)/(weight). The effect is not large and it is probable that values such as those given in Fig. 22 are adequate for practical purposes.

5. CONCLUSIONS

It will be apparent from the wide differences in the results shown here that, for the purpose of a data sheet, information on braking force coefficient can only be given

Surface	30 *m.p.h.*	80 *m.p.h.*	120 *m.p.h.*
Dry Concrete ...	0.75-1.0	0.5 -0.8	0.3-0.6
Dry Grass	0.4 -0.5	0.3 -0.4	0.2-0.3
Wet Grass	0.2 -0.3	0.15-0 25	0.1-0.2

Fig. 17.
Dunlop Estimates: A typical set of figures for *B.F.C.* for tyres in good condition, sliding, locked, might be as given above.

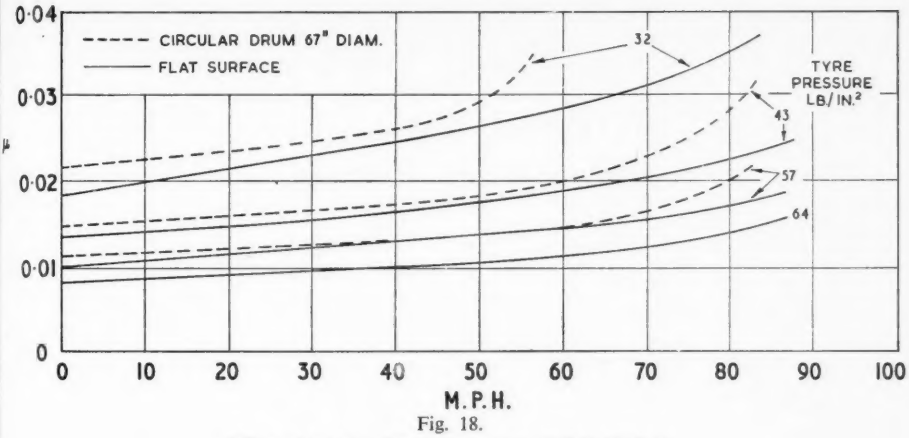

Fig. 18.
Effect of speed and tyre pressure on *R.R.C.* (Ref. 4).

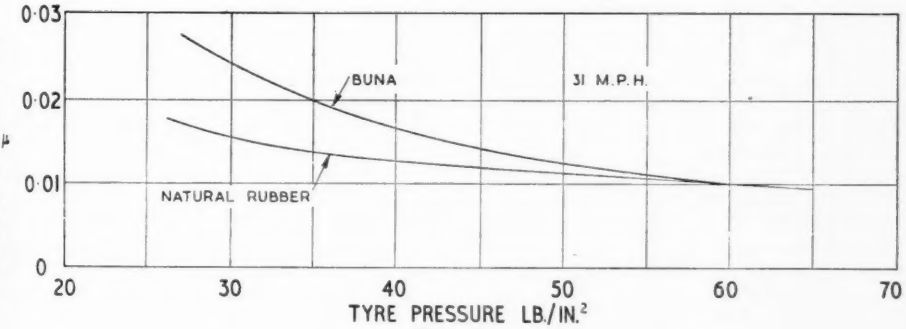

Fig. 19.
R.R.C. (μ) for natural and Buna rubber (derived from Ref. 4).

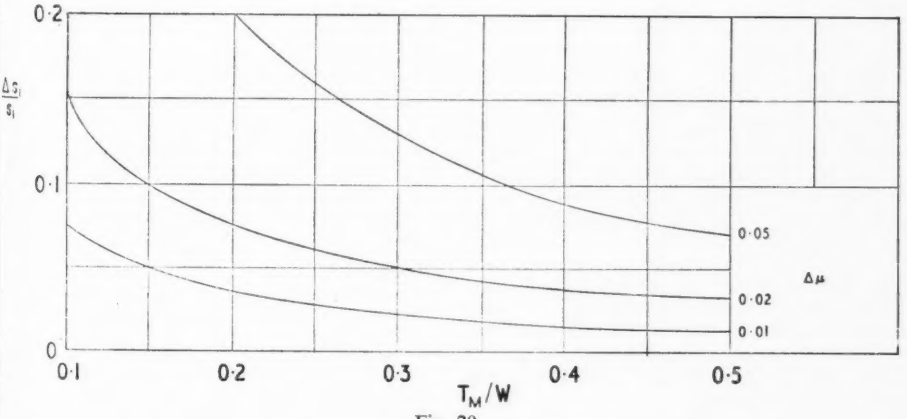

Fig. 20.
Effect of error $\Delta\mu$ in μ on ground run S_1.

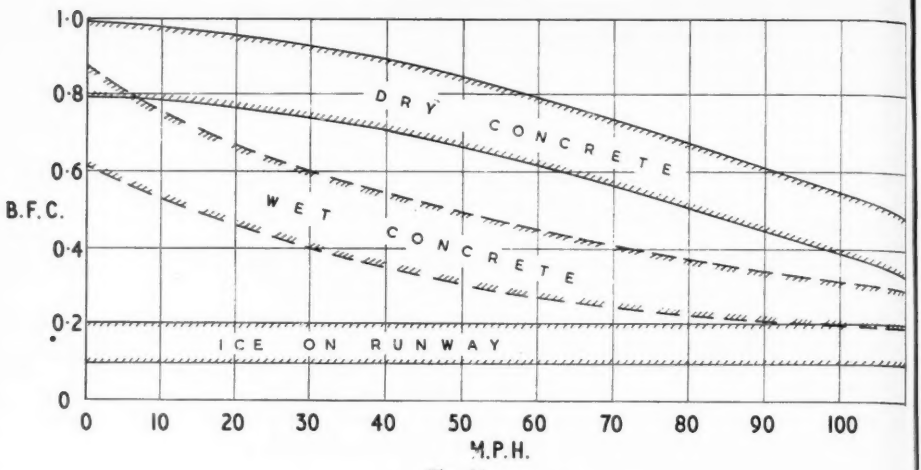

Fig. 21.
Probable variation of braking force coefficient with speed.

in the form of bands within which the *B.F.C.* for various surfaces lies. Such a form is shown in Fig. 21. It is doubtful whether new tests would result in closer limits, since differences due to surface texture will always be present. For estimation purposes, the ideal would be an "agreed curve" on which all estimates would be based.

Since the effect on take-off run of rolling resistance coefficient is small, it is suggested that the values given in Fig. 22, which are in good agreement with data from other sources, could be given in a data sheet, and would be sufficiently accurate for all practical purposes.

Acknowledgments

The author acknowledges the help given to her by Mr. Giles, of the Road Research Board, Mr. Perry and Mr. Gough, of the Dunlop Rubber Company, and by Mr. Ernest Jones, of the Royal Aircraft Establishment; also by the librarians of the Institutions of Civil Engineers and of Mechanical Engineers.

SMOOTH DECK OR HARD SURFACE...	0.02
GOOD FIELD, HARD TURF	0.04
AVERAGE FIELD, SHORT GRASS	0.05
AVERAGE FIELD, LONG GRASS	0.10
SOFT GROUND	0.10-0.30

Fig. 22.
Rolling Resistance Coefficient μ
(From N.A.C.A. Report 450).

References

1. Road Research Laboratory. Studies in Road Friction. (1) Road Surface Resistance to Skidding. (2) An Analysis of the Factors Affecting Measurement. Road Research Technical Papers Nos. 1 and 2. 1937.
2. Moyer. Skidding Characteristics of Automobile Tyres on Roadway Surfaces and their Relation to Highway Safety. Iowa State College Bulletin No. 120. Aug. 1934. (Also contained in "Highway Research Board Proceedings," 1934.)
3. Mathieu. La Glissance des Routes et sa Mesure. May 1936.
4. Report on German Work Relative to the Interaction Between Tyres, Vehicles and Road Surfaces. B.I.O.S. Final Report, No. 1717. Item 22.
5. Bradley and Allen. Factors Affecting the Behaviour of Rubber-tyred Wheels on Road Surfaces. *Proceedings of the Institution of Automobile Engineers.* November 1930.
6. Law. Tyre Requirements for Modern Transport. *Journal of the Institution of Automobile Engineers.* November 1938.
7. Stinson and Roberts. Coefficient of Friction Between Tyres and Road Surfaces. Highway Research Board Proceedings. 13:169—84. 1934.
8. Paustian. Tractive Resistance as Related to Roadway Surfaces and Motor Vehicle Operation. Iowa State College Bulletin, No. 119. 1934.
9. McBrearty. A Critical Study of Aircraft Landing Gears. *Journal of the Aeronautical Sciences.* May 1948.
10. Agg. Tractive Resistance of Automobiles and Coefficients of Friction of Pneumatic Tyres. Iowa State College Bulletin, No. 88.

THE DETERMINATION OF VIBRATION MODES*

by

N. F. HARPUR, B.A.(Eng)., D.I.C., Graduate, R.Ae.S.

AT SOME STAGE in the design of every aeroplane it is necessary to estimate or to measure the resonance modes of vibration. This has not always been the case, but the problems of flutter, control reversal and dynamic loads have increased in importance as speeds have risen. Nowadays, it is an airworthiness requirement that these effects be considered and the aircraft made safe for all conditions of flight. A knowledge of the normal modes of vibration is essential for all accurate estimates of these aeroelastic effects.

Taking flutter as an example, the technique of flutter investigations consists of first determining which combinations of the various possible degrees of freedom are liable to excite dangerous oscillations. Typical degrees of freedom for a wing are bending and twist in each normal mode, aileron deflection and tab deflection; for a tailplane and elevator we might consider tailplane bending or twist, elevator deflection, tab deflection, fuselage bending and twist, and pitching of the whole aeroplane. To make our calculations exact we should consider all possible degrees of freedom in one calculation but, as the work involved is roughly proportional to the factorial of the number of degrees of freedom—a calculation involving only four degrees of freedom probably taking eight weeks—to consider all degrees of freedom would be a life's work.

Most flutter calculations will then depend on a knowledge of the normal modes which may be determined either by resonance tests on the full-scale aircraft, by resonance tests in a vibration model, or by calculation.

Resonance tests on the completed aircraft have the advantage that they include all those details of the structure which are difficult to represent either on a model or by calculations; such details as engine nacelles, propeller stalks, cut-outs, frames, ribs, secondary structure, and so on, all of which may have a profound effect on the higher modes of vibration. These tests also include implicitly the effects of shear deflection of the spars and shear lag across the top and bottom skins. The neglect of these two effects on model tests or in calculations may result in a 10 per cent. error in the 4th mode frequency, rising to 60 per cent. in the 10th mode.

Nevertheless, the full-scale resonance test has three drawbacks. The first is the difficulty of supporting the aircraft in a way which will simulate the airborne condition. The supports must be of a sufficiently low frequency (say less than $\frac{1}{4}$ of the wing fundamental frequency) that they will not affect the normal modes. It has been the practice until recently to support the aeroplane on its undercarriage with the tyres at low pressure, but with large aeroplanes and the consequent lower fundamental frequencies this method of support is restricted to those cases where a node is likely to occur at the undercarriage. Since there is no deflection at a node a support of any frequency may be placed there with no effect on the mode. Air bags may be used to support the aeroplane but there is still some difficulty in securing a low enough frequency while at the same time retaining sufficient stability to prevent the aeroplane sliding off sideways (see Fig. 1).

Another disadvantage of the full-scale resonance test is its inability to give those modes required for flutter. The resonance test is usually made with the aircraft loaded

* Prize-winning paper submitted for the Bristol Branch Junior Members' Competition 1949. Mr. Harpur is with the Aircraft Division of the Bristol Aeroplane Co. Ltd.

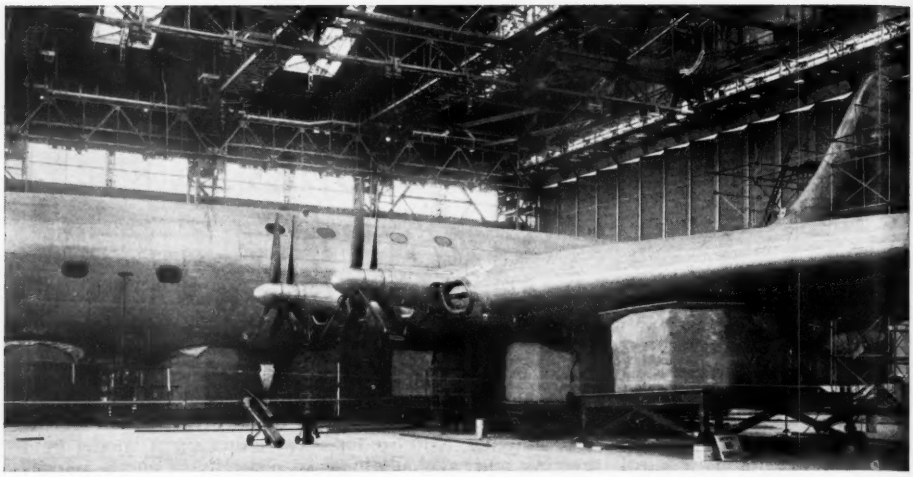

Fig. 1.
Bristol Type 167 supported on air bags for ground resonance testing.

merely by its own weight and a small oscillating load applied by an exciter. The induced stresses will be small compared with the design stresses. A flutter oscillation must be prevented under all likely conditions of flight and we are consequently interested in the vibration modes of the aeroplane in a heavily loaded condition, *e.g.* a 2 *g* pull-out from a dive. Under these conditions it is probable that areas of the wing or fuselage skin will be buckled in compression and areas of the spar webs buckled in shear. The use of a buckled design is more efficient structurally under certain loads but it does involve a reduction of stiffness when the skin or web buckles. Fig. 2 shows the reduction of shear modulus due to buckling of a spar web under shear. Fig. 3 shows the effect of this on the torsional stiffness of a typical wing.

Because of this reduction of stiffness under heavy loads it is probable that the modes of vibration will differ appreciably from those derived from normal resonance tests—certainly the frequencies will be lower. The answer would appear to be to resonance test a heavily loaded structure, but it would require some ingenuity to load the structure up to twice its own weight, while at the same time leaving it free to vibrate in any mode.

These then, are the two problems of resonance testing. The first, the support frequency, is probably the easier to overcome by the use of a better design of air bags or of some type of liquid spring. The second, measurement of the modes under high load conditions, is impracticable.

The third drawback of the full-scale resonance test is that it comes too late for any necessary modifications which it suggests to be cheap and simple.

The use of a vibration model will enable these difficulties to be overcome. The

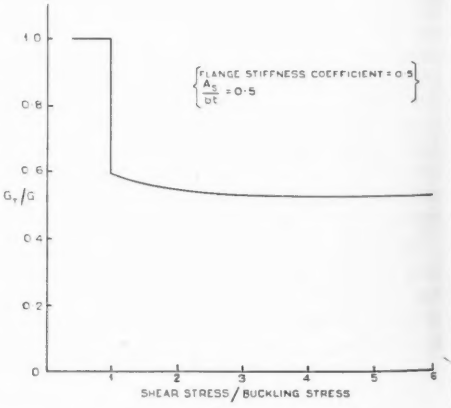

Fig. 2.
Reduction in shear modulus due to web buckling.

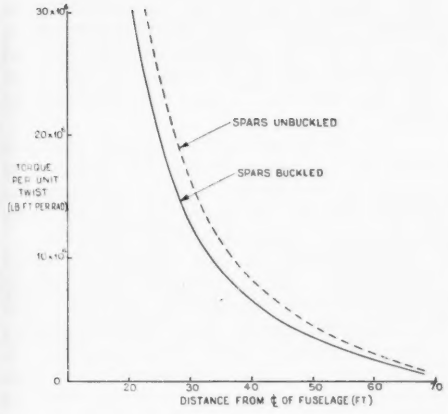

Fig. 3.
Variation of wing torsional stiffness with spar buckling.

support problem is solved by hanging the model on long low frequency cords. In addition the model frequencies will usually be higher than the corresponding aircraft frequencies, further widening the gap between support and resonance frequencies. The problem of determining the modes under high load conditions is solved by arranging the model stiffness to correspond to the aircraft stiffness under these conditions.

The model technique offers other advantages over full-scale resonance tests. It is fairly easy to make changes on the model to investigate variations of mass and stiffness. The model is available for testing over a much longer period and its testing does not clash with other work on the full size aircraft. Perhaps most important of all, results are usually available some time before the aircraft is built and thus modifications are easier.

The model technique has its disadvantages. In order to obtain reliable results for the 5th and higher modes it is necessary to represent the shear deflection and the shear lag effects of the full size aircraft. The simplest way to do this is to make a true scale model geometrically similar to the aircraft. However, one is immediately in difficulties as the scale, which is generally fixed by the space available for testing, may result in model sizes and thicknesses too small for practical manufacture. For example, 0.036 in. spar webs on an aircraft are reduced to 0.003 in. thick sheet on a 1/12 scale model and the tolerances would have to be ± 0.0005 in.

In such cases, one is forced to abandon the true scale model and to design a structure which will represent the aircraft in the more important stiffnesses and masses (see Fig. 4). It is comparatively easy to represent torsional and flexural stiffnesses but the inclusion of shear stiffness tends to produce very

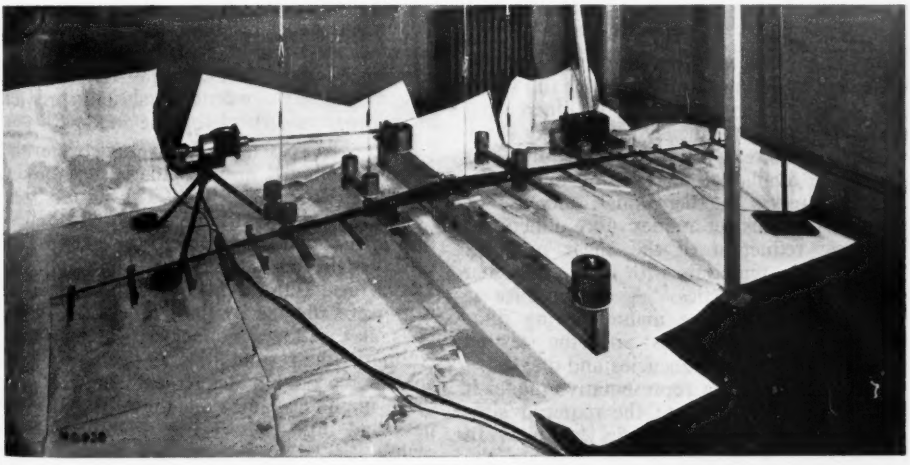

Fig. 4.
Model used for the prediction of the vibration modes of the Bristol Type 175 four-motor civil transport.

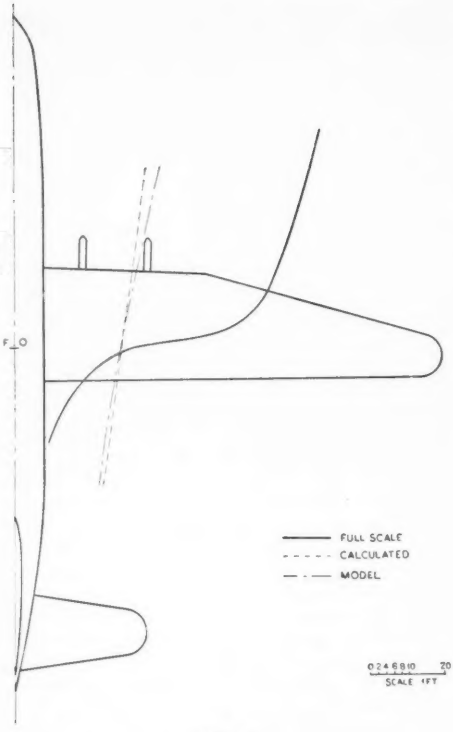

Fig. 5.
Vertical excitation at nose wheel, tanks empty, 2.6 cycles/sec.

thin webs. The webs may be thickened up, while still retaining similarity to the full scale, by increasing length (obviously), increasing mass, increasing frequency or reducing shear modulus. Increase of length is limited by the space available; increase of mass puts up the stresses in the model; increase of frequency makes the modes more difficult to measure; reduction of the shear modulus leads to new materials with new, and often undesirable, properties. A compromise is necessary between the manufacturing difficulties of thin sections and the testing difficulties of high frequencies and masses.

In the design of a representative model it is necessary to calculate the required stiffnesses and to design a model to suit. In some cases it is difficult to estimate the stiffnesses accurately owing to peculiar structural features such as cut-outs or the root effects on a swept-back wing. In such cases the use of a true scale model is a great advantage, since it is merely necessary to scale down all structural dimensions and thicknesses, the model being used to check the calculated stiffnesses as well as the modes.

Thus where possible a true scale model is desirable, relieving us of the necessity of estimating stiffnesses, but a representative model may have to be used where the model thicknesses become too small.

The third way of determining modes is by calculation. This method is generally quicker than model testing and the results are available before those from resonance tests and usually before those from models. There are no support problems to be considered and the stiffnesses used may be those corresponding to any flight condition.

The disadvantages are that the aircraft must usually be idealised into a small number of masses and stiffnesses and the calculations become laborious if such effects as shear lag or engine mounting deflections are included. Furthermore, any variation of stiffness or mass requires a completely fresh calculation.

The limitations of this method are chiefly those of labour, the time for any calculation depending on the number of computors available.

Summarising the three methods of mode estimation it seems that the best approach is to calculate the modes of vibration and to use a vibration model, preferably true scale, to extend the calculations where these become too complicated. The full-scale resonance tests, although not made under the desired loading conditions, should provide an approximate check on the modes.

Figure 5 gives a comparison between the calculated model and resonance test modes for the Bristol Type 167. The nodal lines, *i.e.* the lines along which there is no deflection in the mode, are plotted for a frequency of 2.6 cycles per sec. The calculations and model results agreed well but the resonance tests were affected by the stiffness of the air bags at this low frequency. Fig. 6, which compares the results for 5.23 cycles per sec., shows reasonable agreement between all three methods, indicating that the bag stiffness had little effect. Fig. 7 compares the results for 7.47 cycles per sec.

It should be pointed out here that although the modes were in good agreement as regards shape, the frequencies obtained from the

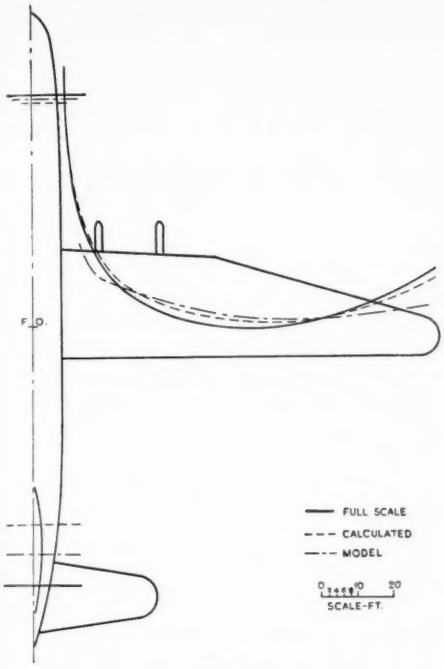

Fig. 6.
Vertical excitation at F.O., tanks empty, frequency 5.23 cycles/sec.

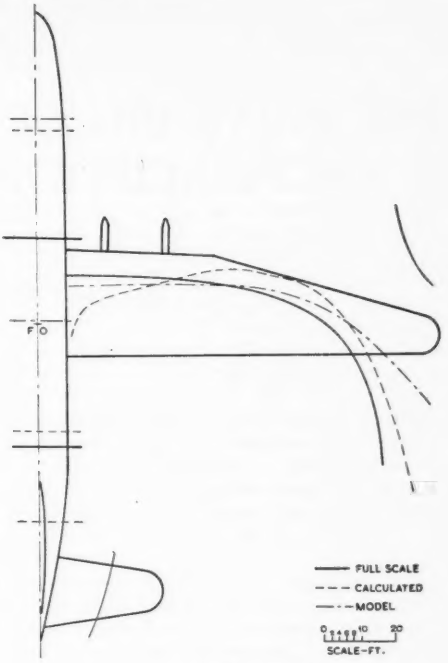

Fig. 7.
Vertical excitation at nose wheel, tanks empty, frequency 7.47 cycles/sec.

resonance tests were higher than the calculated or model test frequencies. This was due to increased aircraft stiffness over that assumed for calculations and for the model.

A method of mode estimation which is likely to be of use in the future is the flight resonance test, the aircraft being vibrated while in the air. This method may enable us to estimate the modes under the actual conditions of support and of loading, but there seem to be two inherent drawbacks—it is impossible to measure deflections directly (we may measure accelerations or stresses) and it will be difficult to get the correct conditions in absolutely still air. Nevertheless development of this method may result in it largely superseding the ground resonance tests.

THE SERVICING OF AIRCRAFT: CHOICE OF PRINCIPLE AND PROCEDURE

by

BLICK CRAWLEY, M.A.

1. INTRODUCTION

This paper discusses a few simple ideas which may be supposed to form, consciously or unconsciously, a schematic basis for the servicing of given aircraft in given circumstances. It is not concerned with engineering technique but rather with the assumptions behind it.

The purpose of an aircraft's upkeep, by which is meant its servicing and maintenance in the widest sense, is to enable the machine to furnish the maximum output of flying work of the required kind and intensity. "Intensity" is used to mean an aircraft's rate of output of flying work in a calendar period.

For commercial aircraft the average intensity required is usually near the maximum that can be sustained at reasonable upkeep expense, because this tends to maximise net profit (or to minimise net loss if there is no profit) by lowering the overheads related to the capital cost of aircraft.

For the machines of an armed force in peacetime the average intensity required is usually less, because there are special reasons against raising it to a commercial level. One of these reasons may be the need to train servicing men "on the job," which slows up the rate of servicing. Another reason is found in the over-riding requirement that the total number of machines owned by the force shall be large enough to allow a quick rise of average intensity if an emergency arises.

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Mr. Crawley is an operational research engineer in the Air Ministry.

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For the machines of an armed force in wartime the required intensity may be high or low and may also vary largely from time to time.

The choice of intensity, in short, is mainly a matter of operating policy. But, whatever intensity may be laid down by operating policy, it is always worth while to sustain the required intensity at reasonable upkeep expense. Upkeep is a matter of servicing and maintenance policies. The present paper is concerned with part of the general basis of servicing policy, *i.e.* with some of the basic matters which servicing policy can and should control with a view to making the upkeep expense reasonable.

The basic matters within the control of servicing policy seem to fall under three heads:

(*a*) The principle upon which the servicing is to be based.

(*b*) The technical procedure adopted for carrying out the servicing principle.

(*c*) The appropriate size and proportionate strengths of technical trades, servicing accommodation, equipment and supplies.

The present paper will treat heads (*a*) and (*b*) only, ignoring (*c*). There is a special reason for this: it is to counteract in servicing policy any tendency to let the administrative details of (*c*) swamp everything else. It is not denied that the last head is important; but in general it is of only secondary importance until (*a*) and (*b*) have been settled. Before deciding how a programme is to be carried out it is well to know exactly what the programme is.

2. OPTIMUM SERVICING PRINCIPLE FOR MACHINERY IN GENERAL

For almost any given industrial machinery in given circumstances, certain routine duties

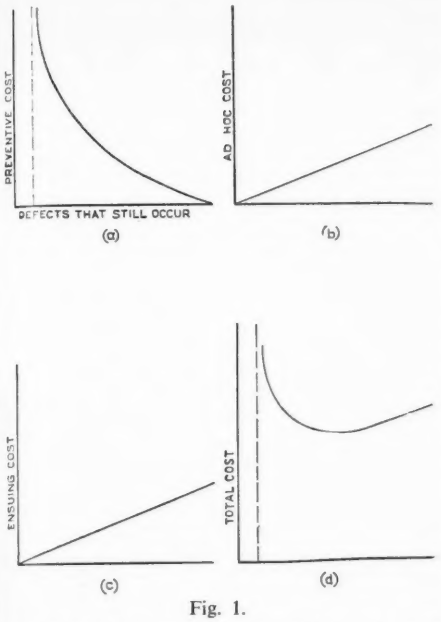

Fig. 1.

Sketch graphs representing variation of costs against defects of typical machinery. The horizontal plots always represent defects that still occur in spite of preventive work. The vertical plots represent:—

(*a*) Direct cost of preventive work done.
(*b*) Direct cost of *ad hoc* work on defects that still occur.
(*c*) Ensuing cost of defects that still occur.
(*d*) Total costs, direct plus ensuing.

The condition for minimum total costs is not critical.

pertaining to its upkeep are inevitable and fixed. These duties consist of routine fuelling, oiling, loading, and so forth, on the one hand, and of statutory safety precautions (if applicable) on the other. They cannot be changed without changing respectively the pattern of the machinery or the Government regulations (where these exist). Accordingly there is no question of choosing a servicing principle for such routine duties; they are here taken for granted as invariable.

It remains to choose a principle for carrying out the rest of the servicing at reasonable expense: to strike an economic balance between the amount of prearranged "inspection"—preventive work, consisting in the examination of parts at predetermined intervals and their "rectification" (repair or replacement) as deemed advisable—and the amount of "first-line servicing"—day-to-day *ad hoc* work rendered necessary by unforeseen failures of parts.

It is perhaps obvious that, in general, an attempt to replace *ad hoc* work entirely by inspections will probably fail and will certainly be expensive. (This is particularly true of aircraft, in which it seems certain that no amount of preventive work can entirely eliminate random defects.) Likewise an attempt to replace inspections entirely by *ad hoc* work will generally prove expensive. The chief reason for the latter is that the total expenditure to be taken into account must cover not only the direct cost of the examination and rectification, but also all ensuing cost incurred through the machinery's unexpectedly going out of commission: loss of output, wasted overheads, wages paid to operators standing idle, compensation for public and private damage, and so forth.

Direct costs are high with the extreme (generally absurd) principle of nothing but prearranged inspections, and tend to fall as larger ratios of *ad hoc* to preventive work are introduced—at any rate over a certain range. Ensuing cost varies in a different way; the higher the ratio of *ad hoc* to preventive work, the higher the cost becomes.

The optimum servicing principle to choose is that which makes the total expenditure, the sum of the direct costs and the ensuing cost, a minimum (see Fig. 1).

For machinery in general the determining of the correct choice is a somewhat complicated business. The engineers have first to estimate, on the basis of accumulated technical data and experience, what is the maximum amount of preventive work—prearranged inspection—that would be worth doing from the technical viewpoint. (This does not imply an attempt to abolish *ad hoc* work entirely.) They have then to decide in consultation with the accountants, preferably by means of a regression analysis of total expenditure,* what parts of these technically worth-while inspections it is actually cheaper in overall expenditure to replace by *ad hoc* servicing. The general problem is further complicated by the need to consider, at the same time, the relative costs of different technical procedures (see

* *See*, for example, Philip Lyle's *Regression Analysis of Production Costs and Factory Operations*, 1944 (Oliver & Boyd). The book does not deal with this problem of servicing, but it does illustrate the general methods and usefulness of regression analysis.

section 5). The precise choice may sometimes turn out to be not critical, as in the example illustrated in Fig. 1.

The preceding paragraph having indicated the general method of making the correct choice, the matter of machinery in general will not be pursued further. For aircraft in particular it will be seen that the correct choice is much more easily determined.

3. OPTIMUM SERVICING PRINCIPLE APPLIED TO AIRCRAFT

Servicing policy for aircraft is in the fortunate position of not having to consider ensuing cost at all. Only the direct costs need be considered. The reason is that the ensuing cost of unforeseen failures of aircraft is known to be so high that there is universal tacit agreement to do everything reasonably possible to avoid them (see Fig. 2).

With aircraft, therefore—as with a few other special types of machinery—the correct choice for the optimum servicing principle is simply to do the maximum amount of preventive work that is worth doing from the technical viewpoint. The question remains: How is this maximum worth-while amount to be estimated?

4. ESTIMATING THE MAXIMUM WORTH-WHILE AMOUNT OF PREVENTIVE WORK FOR AIRCRAFT

Regarding the liability to failure of the various parts of an aircraft, every part can be classified in *both* of two ways. The first classification deals with " predictability ":

(1*a*) Either practical experience shows that the part has a reasonably constant and predictable lifetime (measured in flying hours, sorties or calendar period as may be appropriate),

(1*b*) Or, practical experience shows that the part's lifetime is random and unpredictable.

The second classification deals with " inspectability ":

(2*a*) Either the practically observable condition of the part (*e.g.* wear, cracks, corrosion, and so on) gives warning of the probability of failure, in which case the part is " inspectable,"

(2*b*) Or, the practically observable condition of the part gives no warning of the probability of failure, in which case the part is " uninspectable."

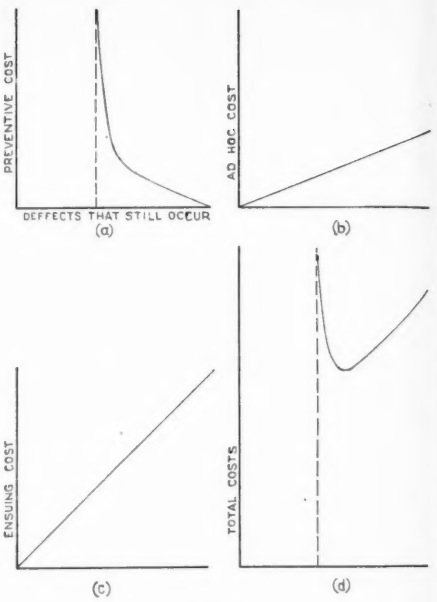

Fig. 2.

Sketch graphs representing variation of costs against defects of aircraft. Key as in Fig. 1. The condition for minimum total costs is critical.

A duty involved in efficient servicing policy is continually to collect from servicing organisations up-to-date information on the predictability and inspectability of aircraft parts.

Parts of mechanism that suffer regular wear during use are generally (1*a*) predictable and (2*a*) inspectable. Sometimes they are (1*a*) predictable and (2*b*) uninspectable. All such parts can be dealt with fairly easily by means of periodic examination or periodic rectification or both. It is for servicing policy to study the data continually collected upon predictable parts, and to apply the findings in new rules laid down from time to time regarding the nature and frequency of periodic inspections.

Parts that are (1*b*) unpredictable are more troublesome. If they are (2*a*) inspectable, they should be examined as frequently as is practicable if they are important, but not at all if they are unimportant. This again is a matter for servicing policy to consider, in the light of collated technical data and experience, and to apply in the rules laid

down from time to time for daily and pre-flight inspections.

Parts that are (1*b*) unpredictable and (2*b*) uninspectable are never worthy of a pre-arranged detailed examination at all, no matter how important they may be. If they are important they should be given a simple test—not a detailed examination but merely a trial operation—at frequent intervals. If they are unimportant they should be left entirely alone. Servicing policy should deal appropriately with these too, in the rules laid down from time to time for daily and pre-flight inspections.

Excluding mechanism that suffers regular wear during use, most parts of an aircraft appear to be unpredictable and uninspectable. To give such parts a detailed examination at any time means a waste of servicing effort and of flying effort. Its only conceivable justification is the psychological one of imbuing air crews with a sense of security, and even this is questionable if the air crews are experienced.

The preceding paragraphs of this section represent a fuller and more precise expansion of an old idea (which, as a matter of fact, can be applied for estimating what would be the maximum worth-while amount of preventive work with any machinery whatever). It is probable, indeed, that the general lines of actual servicing policy are already conditioned, consciously or unconsciously, by these commonsense principles. But there is always the danger of their being confused or distorted by other matters: the question of the appropriate size and proportionate strengths of technical trades, servicing accommodation, equipment and supplies (which is a secondary matter); the instinctive feeling that if a part is important it must have a detailed examination at frequent intervals (which is misleading); a reluctance to change traditional rules.

It is particularly important for servicing policy to resist the natural tendency of any prearranged inspection system to become, with the lapse of time, traditional, formal and misleading. Unless the tendency is frequently checked the work will become needlessly slow and expensive, because servicing men will spend time in regularly looking, by order, at parts whose appearance tells them nothing, and in regularly renewing, by order, parts which adequate data would prove do not need renewing—" preventive " work that in fact prevents nothing. No preventive work is worth doing unless it is justified by sound reasons and carried out on a sound plan. The rapid rise in moving toward the extreme left of the curves (*a*), in Figs. 1 and 2, represents the rapidly diminishing returns which result from doing excessive preventive work that is technically not worth while.

Thus, as has been indicated above, the periodic inspections of an aircraft should be planned around its predictable parts, and the daily and pre-flight inspections should be planned around its unpredictable parts. The plan will depend broadly upon the type of aircraft and the flying work to be done, and it will need revision from time to time as fresh data are collated.

The plan, when made, represents a practical estimate of the maximum worth-while amount of preventive work, which is the correct choice for the optimum servicing principle in the case of aircraft. It is obvious that in practice one cannot undertake to rectify every predictable part at exactly the " right " moment: every such rectification will be planned to take place at some convenient earlier inspection.

It is also obvious that the method of this section cannot be applied during the early life of a novel type of aircraft differing widely from any type that has previously existed. The only course then is to depend solely upon general engineering experience and analogy, until a sufficient body of servicing statistics has been collected to enable a start to be made upon classifying the new machine's parts in terms of predictability and inspectability.

5. DETERMINING THE TECHNICAL PROCEDURE FOR SERVICING AIRCRAFT

Because, as previously stated, the ensuing cost of unforeseen failures of aircraft outweighs most other matters, it is permissible when considering the servicing of aircraft to determine the servicing principle before discussing the technical procedure. The former having been determined, the latter will now be dealt with in general terms.

Two points are chiefly relevant. First, the technical procedure of having servicing work performed by organised gangs at predetermined intervals is known to be less costly than allowing an equal amount of *ad hoc* work to be done unforeseen and piecemeal. This point is not a substitute for the

preceding section—it is useless to apply "preventive" methods to parts that are genuinely unpredictable and uninspectable—but it does enable any remaining matters to be resolved which may have been left doubtful, through lack of adequate statistics, when considered on the lines of the preceding section.

Even in the field of *ad hoc* work alone, an analogous argument shows that servicing cost will be reduced if it is practicable merely to note and "save up" trifling defects which arise at random, reserving action until a serious defect arises or a periodic inspection becomes due. Because it is cheaper and quicker to rectify a number of defects at one time, rather than each one separately at different times, a saving-up procedure of this kind economises both servicing effort and flying effort. This has been proved in practice. The criticism may be made that in an aircraft there can be no such thing as a "trifling defect": this turns upon questions of definition and would take too long to discuss here. Certainly a saving-up procedure must never be allowed to interfere with flying safety.

Secondly, it is generally a quicker technical procedure to replace a condemned part by a new or reconditioned spare from stock—"repair by replacement"—than to repair it on the spot. Technical judgment and some rough accounting work is needed to decide for which parts, and in what circumstances, repair by replacement shall be prescribed.

6. CONCLUSION

The above represents an attempt to crystallise the fundamentals of servicing policy for aircraft, namely, first to determine the optimum servicing principle and then to determine the optimum technical procedure, before going on to the secondary stage of considering numbers and quantities.

Even in this deliberately limited field there are inevitably some questions connected with servicing personnel and accommodation—for example, the level of skill to be expected among the men, and the kind of equipment to be expected at out-of-the-way depots. Such questions, however, are generally concerned with quality rather than with numbers: they are not matters of administrative detail. The answers should already be broadly familiar to those who lay down servicing policy, being in fact a part of their general technical experience and engineering "know-how." On this basis they can still begin by determining principle and procedure, as indicated, without first involving themselves in a morass of administrative detail.

(Correspondence on this paper will be welcomed.—ED.)

REVIEWS

TECHNOLOGY OF LIGHT METALS. A. von Zeerleder. Elsevier Publishing Co. Inc., New York. 1949. $7.50 net. 366 pp. Illustrated. Index.

The history of aluminium really dates from its discovery by Wöhler in 1827. Until nearly the end of the Victorian period, however, it remained a scientific curiosity of largely unsuspected potentialities. Then, the simultaneous but independent invention, by Hall in America and by Héroult in France, of the electrolytic process for the reduction of alumina, completely changed the position. The World had been told how to obtain aluminium from its oxide. This, however, was not enough, for the latter in a state of sufficient purity and quantity does not occur in Nature. On the other hand, Bauxite and certain other hydrated oxides of aluminium, in a far from pure state, are fairly widely and generously distributed. The economic production of the metal depended on the economic supply of its oxide, virtually uncontaminated with other matter. This was soon provided by the Bayer process, which, like that of Hall and Héroult, functions to-day, much as it did when first brought into being.

The metal so produced, at once found both chemical and engineering applications, but neither it nor its early alloys had mechanical properties suitable for many structural applications. It was not until the early years of this century that the metallurgical researches of Conrad Claessen, Alfred Wilm and others, enabled aluminium alloys to enter in a big way into the then embryonic world of aviation, first as the structural material of airships and later as that of their heavier-than-air supplanter. To-day, approximately a century and quarter after the initial discovery of the metal, we find it in the ascendant in almost every industrial field.

In 1933, Professor A. von Zeerleder, inspired by this success story of slow beginnings, followed by ever-increasing acceleration, wrote "Die Technologie des Aluminiums und seine Leichtleigerungen." To-day, there is available in English by the same author, "Technology of Light Metals." The first work was a worthy and notable achievement. The second is more than a disappointment. In some 100 pages von Zeerleder deals with the production of both aluminium and magnesium. He outlines the theory of alloys and describes, generally by names little known in this country, a number of them. He gives a dissertation on testing and on physical properties and another, no more satisfying, on the chemical ones and on methods of analysis. He even enunciates what he believes to be the principles of design and construction.

In the 250 pages of text which remain, the author discourses on the economics of melting, methods of block and billet casting, the production of castings, rolling mills, forgings and forging plant, extrusion and impact extrusion, wire manufacture, welding, riveting, surface treatments and Heaven knows what besides. Of course, the book is more than superficial and this is an understatement. It is often almost parochial. von Zeerleder sees the metallurgical achievements of Switzerland writ large, but of those of North America his vision is dim indeed.

In a single diagram he gives some of the physical properties of Peralumin, Silafont, Anticorodal, Alufont and Unifont. These are names by no means familiar in our mouths as household words. On no single page, however, does he so much as mention such aircraft alloys as D.T.D. 363A and 683 or any others, like 75S, of similar composition. To use a literary analogy, this, in the eyes of the British aeronautical engineer, is surely like dissertating on such minor characters as the first and second gravedigger while totally neglecting Hamlet, Prince of Denmark? If Professor von Zeerleder's book finds grateful readers, they will not be members either of the British Aircraft Industry or of the light alloy one—P.L.T.

A TEXTBOOK OF RADAR. By the Staff of the Radiophysics Laboratory Council for Scientific and Industrial Research, Australia. Chapman and Hall Ltd., London. 1948. £2 10s. net. 579 pp. Illustrated.

The staff of the Radiophysics Laboratory of the Council for Scientific and Industrial Research in Australia have produced a valuable and comprehensive work of reference.

The book is more than a textbook of Radar, for five-sixths of the subject matter deals with basic tools which have wider application than those of Radar; about one-sixth is devoted to Radar systems. The emphasis of the book is very much towards the centimetre rather than the metre region, and to the corresponding techniques.

After two general chapters the book treats Magnetrons very fully, although here naturally it is rather difficult to keep up with the rapidly developing theoretical side.

Chapters on Triode Power Oscillation and Modulation lead to a full treatment of transmission, resonator theory and technique, and aerials. Local oscillators and mixers are well treated, and the radar techniques are rounded off by three chapters on circuitry. In that on amplifiers there is little reference to feedback or stability criteria. The chapter on display circuits deals briefly with clamps but more fully with time base generators, and ranging circuits.

Automatic Ranging Circuits are thoroughly covered, although the methods of velocity memory could be improved by the use of Miller integrators rather than simple R.C. circuits.

The final sixty pages deal with Radar systems and cover most of the systems evolved during World War II. The treatment is not detailed but salient points are brought out. The requirements of civil aviation are dealt with briefly.

Perhaps the most important parts of the book are those which deal with the special components which have been evolved for use in Radar systems; their evolution and theory have been most carefully described. The book should be valuable to all concerned with microwave communication.—A.M.U.

THE ELEMENTS OF AERODYNAMICS OF SUPERSONIC FLOWS. Antonio Ferri. The Macmillan Company, New York. 1949. $10.00 net. 434 pp. 248 figures. Appendix and Index.

Detailed accounts of the elementary theory of inviscid supersonic flow in book form are still uncommon, and this book provides the student of supersonic aerodynamics with a useful work on the subject.

In the first half of the book, after a brief development of the general equations, two-dimensional flows are treated in detail. There are chapters on characteristics, shock-waves, interaction and reflection of shock waves and expansion waves, and supersonic wing profiles. Two useful chapters on effusors and diffusors, together with an account of methods of measurement of physical quantities in a supersonic flow, will make the book valuable to the designer and user of supersonic wind tunnels. The remaining half of the book is devoted to a consideration of three-dimensional flows, with treatments of axially symmetrical flows and yawed bodies of revolution, and aerodynamic forces on supersonic wings. Tables for the analysis of supersonic flows, together with charts of characteristics and shock polars suitable for graphical constructions, are given at the end and add considerably to the usefulness of the work.

About three-quarters of the book is devoted to non-linear theory, the treatment of which is generally good. Minor points of criticism are that characteristics and shock waves are not introduced in a very convincing manner, and that the reader might be led to believe that an envelope of characteristics is the position of the associated shock wave.

The treatment of linearised theory is disappointing. The methods used are those which were current before the last war and, in view of the progress made since then in this branch of the subject and the lack of books dealing with it, it is a pity that the author was unable to give an up-to-date presentation.—G.N.W.

GAS TURBINES FOR AIRCRAFT. F. W. Godsey and L. A. Young. McGraw-Hill Book Co. Inc., New York. 1949. $4.50 net. 355 pp. Illustrated. Appendix. Index.

Into the 350 odd pages of this book is packed a great deal of useful material. A fair and balanced picture of gas turbine design and performance has been achieved, although some rearrangement of the chapters would have made for a more logical sequence in presentation. For example, the second chapter dealing with aircraft propulsion could, with advantage, have been placed at the end of the book, and its place taken by part of the eighth chapter on gas turbine cycles, in order to group the subject matter on fundamentals in the early part of the book. Apart from such criticism, the subject matter is well treated and presented clearly.

The first two chapters deal with basic aerodynamics and aircraft propulsion. In the former, continuity might have been aided by the omission of the short thermodynamic discourse and the authors could well have extended the treatment of the isolated aerofoil to include an introduction to aerofoils in cascade, thus providing a link with the later chapters on compressor and turbine design. The two chapters are followed by one on gas flow which sets out clearly the usual one-dimensional thermodynamic theory, but is most useful in presenting the theory of gas flow with heat addition and a sound treatment of shock wave phenomena.

The next chapters dealing with compressors, combustion chambers and turbines are little short of admirable. The modern aerodynamic approach to compressor and turbine design is well to the fore, illustrated by means of practical examples. Space is found for a very useful introduction to the more physico-chemical aspects of the combustion process. Mechanical design and its problems finds a place in these chapters which cannot fail to present to the serious reader, a well-balanced picture of the whole subject of gas turbine component design.

In the remaining part of the book, we find gas turbine cycles and performance theory well covered, and descriptions and simple theoretical treatments are given of the many variants of the simple form of gas turbine engine, including engines with after-burning or re-heat. The last chapter very aptly deals with present-day development and is certainly as up-to-date as could be expected in a book of this description.

Altogether, the book can be recommended as a comprehensive and well-written treatise on the theory of aircraft gas turbine design and performance and its practical application. The authors and publishers are to be congratulated on making available a book of such usefulness.—S.J.M.

SPEED CONTROL-LINE MODELS. R. H. Warring. Percival Marshall and Co. Ltd. 1949. 10s. 6d. net. 207 pp. Illustrated. Appendix.

High speed control-line flying is a specialised subject– as the author points out—and its present state of near-ultimate development is almost entirely due to the efforts in the post-war years of American modellers sponsored by the model-engine manufacturers. Had Mr. Warring included data on individual performances of the British and American models described, and a comparison of current speed records and average contest performances in comparable motor capacity classes, the contrast would make it only too clear that the art of speed flying is far from being the cut and dried affair which a book of this type inevitably suggests. Indeed, duplicates of American record holders, fitted with American engines, have invariably

failed to produce even comparable speeds in this country, emphasising that the aerodynamics of the model is only half the story.

However, this half is dealt with in the usual systematic manner of the author and a useful mass of data on individual details and the many common features of the best present-day models is presented. Technically, the details are dealt with somewhat loosely (there is an annoying error in Fig. 41) and the reviewer considers that, in view of the incomplete nature of all the semi-theoretical matter, the space could have been better devoted to presenting a more colourful picture of the "outdoor" side of this competitive hobby and sport.—F.E.D.

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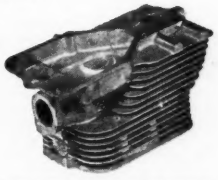

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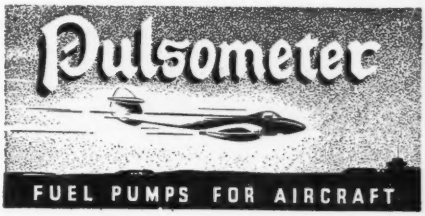

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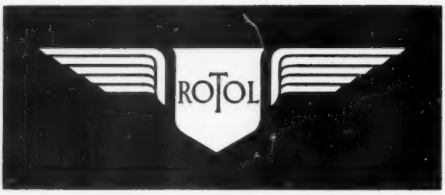

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NOTICES DECEMBER 1949

CHRISTMAS 1949

The President, Sir John Buchanan, the Council and the staff of the Society wish all members, at home and overseas, a very happy Christmas, and a Prosperous New Year.

CHRISTMAS HOLIDAYS

The Library and Offices of the Society will be closed from 5 p.m. on Friday, 23rd December until Wednesday, 28th December, at 9 a.m.

CONTENTS OF DECEMBER JOURNAL

Aerodynamic Balancing of Propellers, H. L. Milner, Wh.Sc., A.M.I.C.E., F.R.Ae.S.
Coefficients of Friction, E. C. Pike, M.A., A.F.R.Ae.S.
The Determination of Vibration Modes, N. F. Harpur, B.A., D.I.C., Graduate R.Ae.S.
The Servicing of Aircraft: Choice of Principle and Procedure, Blick Crawley, M.A.
Reviews.
Index to Volume 53 1949.

The Council have set aside an annual sum of £250 *for the award of premiums for papers published in the Journal and hope that members and non-members of the Society will contribute papers on their own special subjects.*

THE AERONAUTICAL QUARTERLY

Part III of " The Aeronautical Quarterly " is now available and may be obtained from the offices of the Society, 4 Hamilton Place, W.1, at 7s. 9d. each to members of the Society, post paid, or 10s. 3d. each to non-members, post paid.

The contents of Part III are:—

Surging of Axial Compressors	H. Pearson and T. Bowmer
Strain Measurement by X-Ray Diffraction Methods	G. B. Greenough
Buckling of a Longitudinally Stiffened Flat Panel	H. L. Cox and J. R. Riddell
Approximate Calculation of the Laminar Boundary Layer	B. Thwaites

Copies are still available of Parts I and II.

The contents of Part II are:—

Displacements of a Linear Elastic System under a Given Transient Load	D. Williams
Skin Friction in the Laminar Boundary Layer in Compressible Flow	A. D. Young
The Measurement of Gas Turbine Combustion Efficiency by Gas Analysis	L. J. Richards and J. C. Street
A Simplified Theory of " Simple Waves "	A. Ghaffari

The contents of Part I are:—

Control Reversal Effects on Swept-Back Wings	H. Templeton
Calculation of Downwash Behind a Supersonic Wing ..	G. N. Ward
Estimation of the Effects of a Parameter Change on the Roots of Stability Equations	K. Mitchell

Flutter of Systems with Many Freedoms	W. J. Duncan
Note on Propeller-Turbine Reduction Methods	E. C. Pike
Determination of the Drag of Jet-Propelled Aircraft in Flight	G. W. Trevelyan and D. R. Blundell
Notes on the Linear Theory of Incompressible Flow Round Symmetrical Swept-back Wings at Zero Lift	F. Ursell

The special attention of members is drawn to the fact that a strictly limited edition only of " The Aeronautical Quarterly " is printed and numbers cannot be reprinted in any circumstances.

MEMBERS' NEW APPOINTMENTS

It is regretted that Dr. J. J. Green's new appointment as Deputy Director General of the Canadian Defence Research Board and Scientific Adviser to the Chief of the Air Staff was incorrectly given in the October Journal.

ELLIOTT MEMORIAL PRIZE

The Elliott Memorial Prize has been awarded to 583524, Robertson, A. G.—F.II.A, the Aircraft Apprentice of the January 1947 Entry who obtained the highest marks in the General Studies Examination.

LECTURE PROGRAMME 1949-50

MAIN LECTURES

(*To be held at* 6 *p.m. at the Institution of Civil Engineers, Gt. George Street, S.W.*1, *unless otherwise stated. Tea will be served at* 5.30 *p.m.*)

Thursday, 15th December 1949—JOINT LECTURE WITH THE INSTITUTE OF NAVIGATION—Navigational Systems and Instrument Aids, Dr. D. E. Adams, B.Sc., A.Inst.P., and Dr. A. N. Uttley, B.Sc., Ph.D.

Thursday, 9th February 1950—The Producing of a Prototype Aircraft, C. T. Wilkins, A.F.R.Ae.S.

Thursday, 16th March 1950—Air Survey, Group Capt. F. C. V. Laws, C.B., C.B.E.

Thursday, 30th March 1950—Modern Methods of Testing Aero-Engines and Power Plants, A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S.

Thursday, 13th April 1950—The Berlin Air Lift, Air Commodore J. W. F. Merer, C.B.

Thursday, 27th April 1950—Recent Developments in High Speed Research in the Aerodynamics Division of the N.P.L., J. A. Beavan, M.A.(Cantab), A.F.R.Ae.S., and D. Holder—**at the Chemistry Lecture Theatre, Manchester University, at 7 p.m.**

Thursday, 4th May 1950—3rd LOUIS BLERIOT LECTURE—IN PARIS, Sir Frederick Handley Page, C.B.E., F.I.Ae.S., Hon.F.R.Ae.S.

Thursday, 25th May 1950—38th WILBUR WRIGHT MEMORIAL LECTURE, Sir Richard Fairey, M.B.E., F.R.Ae.S.

SECTION LECTURE

A Joint Lecture with the Physical Society will be held in the Library of the Royal Aeronautical Society, 4 Hamilton Place, at 5.30 p.m. (tea 5 p.m.) on Thursday, 19th January 1950. The Subject will be: Acoustical Aspects of Recent Aerodynamic Research.

Short contributions will be given by:—

Mr. N. Fleming on Supersonic Noise of Aircraft.

Mr. H. B. Squire on Noise and Vibration in Wind Tunnels.

Dr. E. G. Richardson on Periodic Boundary Layers.
Mr. A. Robinson on Acoustic Analogues in Calculating Supersonic Resistance.
These will be followed by a General Discussion.

BRANCH LECTURES—AUTUMN SESSION 1949

BELFAST BRANCH

Tuesday, 13th December 1949—Fatigue of Metallic Materials, Major P. L. Teed, A.F.R.Ae.S.

Tuesday, 24th January 1950—Recent Developments in Aircraft Production Engineering, Professor J. V. Connolly, B.Eng., F.R.Ae.S.

In the Central Hall, College of Technology, Belfast, at 7 p.m.

BIRMINGHAM BRANCH

Friday, 6th January 1950—Annual Dinner—*at the White Horse Hotel.*

BRISTOL BRANCH

Monday, 16th January 1950—Operational Factors Affecting the Design of Future Civil Air Transport Aircraft, C. Dykes, M.A., A.F.R.Ae.S.

In the Conference Room, Bristol Aeroplane Co. Ltd., Filton House, at 6 p.m.

BROUGH BRANCH

Wednesday, 14th December 1949—Practical Problems in the Design and Operation of Naval Aircraft, Lt.-Cdr. E. M. Brown, O.B.E., D.F.C., R.N.

Wednesday, 11th January 1950—Members' Lecturette Night.

In the Lecture Hall, Electricity Showrooms, Ferensway, Hull, at 7.30 p.m. Admission by ticket only, because of limited accommodation.

COVENTRY BRANCH

Wednesday 14th December 1949—Film Evening on Aircraft Materials.

Wednesday, 18th January 1950—High Speed Flight, A. D. Young, A.F.R.Ae.S.

In the Trinity Hall, Ford Street (near Pool Meadow), Coventry, at 7.30 p.m.

GLASGOW BRANCH

Tuesday, 20th December 1949—Annual General Meeting.

Tuesday, 24th January 1950—Debate: Civil Aviation is a Luxury.

At the St. Enoch Hotel, Glasgow, at 7.30 p.m.

GLOUCESTER AND CHELTENHAM BRANCH

Wednesday, 14th December 1949—*at Gloucester*—Problems of High Speed Flight, H. Davies, M.Sc., F.R.Ae.S.

Thursday, 12th January 1950—*at Cheltenham*—Recent Developments in Aircraft Production Engineering, Professor J. V. Connolly, B.Eng., F.R.Ae.S.

Gloucester Meetings (Wednesdays) are held in the Wheatstone Hall, City Library, Brunswick Road, at 7.30 p.m.

Cheltenham Meetings (Thursdays) are held in the Empire Hall, North Street, at 7.30 p.m.

ISLE OF WIGHT BRANCH

Thursday, 15th December 1949—Annual General Meeting. Followed by a film show.

Thursday, 12th January 1950—Discussion Evening. Control Systems.

In the Saunders-Roe Sports and Social Club at 6 p.m.

LUTON BRANCH

Wednesday, 14th December 1949—Annual General Meeting and Presidential Address.

Meetings are usually held at the George Hotel, Luton, at 7.30 p.m.

PORTSMOUTH BRANCH

Friday, 16th December 1949—Recent Developments in Aircraft Production Engineering, Professor J. V. Connolly, B.Eng., F.R.Ae.S.

Friday, 13th January 1950—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.

In the Lecture Room, Central Library, at 7 p.m.

PRESTON BRANCH

Thursday, 15th December 1949—Annual Dance, 8 p.m.—1 a.m. *at Worsley's Ballroom, Market Street, Preston.*

SOUTHAMPTON BRANCH

Wednesday, 11th January 1950—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.
In the Physics Lecture Theatre, University College, at 7 p.m.

WEYBRIDGE BRANCH

Wednesday, 21st December 1949—Round the World in 90 days (a record of a 40,000 mile air journey), W. Courtenay, M.M., A.R.Ae.S.
Wednesday, 11th January 1950—Brains Trust.
At Vickers-Armstrongs Ltd., Weybridge Works, at 6 p.m., unless previous notice is given.

ASSOCIATE FELLOWSHIP EXAMINATIONS—DECEMBER 1949

The Associate Fellowship Examination will be held on 19th, 20th, 21st and 22nd December 1949, at Huxley Building of Imperial College of Science and Technology, Exhibition Road, South Kensington. The examination will also be held on those dates at various centres abroad. All candidates will receive a time-table and full instructions individually.

ANNUAL SUBSCRIPTIONS

Members are reminded that their annual subscriptions become due on 1st January 1950. The rates are:—

	Home			Abroad		
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Fellows	5	5	0	4	4	0
Associate Fellows	4	4	0	3	3	0
*Associates	3	3	0	3	3	0
Graduates (aged under 26)	2	2	0	2	2	0
Graduates (aged 26 and over)	2	12	6	2	12	6
Students (aged under 21)	1	1	0	1	1	0
Students (aged 21 and over)	1	11	6	1	11	6
Companions	3	3	0	3	3	0
Founder Members	2	2	0	2	2	0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership.

Remittances should be made payable to the Royal Aeronautical Society.

CHANGE OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

JOURNAL BINDING

The new prices of binding of Journals will be as follows:—

	s.	d.
1949 Volume (including packing and postage)	15	6
Previous Volumes (including packing and postage) ..	17	0
Cases for 1949 Volume	6	6

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Requests for cases, with remittances, should be sent to the Secretary at the Offices of the Society.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Fellow

Jules Louis Albert Jarry (from Associate Fellow).

Associate Fellows

William Francis Andrews, William Baillie, Owen Richard Ballard (from Graduate), Roy Desmond Boot (from Graduate), Charles Edward Fraser Brown, Alan Colin Campbell Orde, Donald Clayson (from Associate), Harold Murray Ellins (from Graduate), Roger Quentin Eden Eden (from Graduate), Ernest Malcolm Elliott, Edward William Fidler (from Companion), Jack Ford (from Graduate), Robert Frederick Freitag, Thomas William Funston, Raymond Dennis Green, Stanley Peter Hawes (from Graduate), William Geoffrey Heath (from Graduate), Jonathan Huddart, John Alexander Jefferson-Loveday (from Graduate), Francis Henry Keast (from Graduate), Wilfred James Kelly (ex-Student), Marcel Jules Odilon Lobelle, Norman Wilkinson McCue, Rolf Frederick Marshall (from Student), Eric John Martin (from Associate), Bernard Alexander Masters, Albert Ronald Mettam (from Graduate), Dennis James Moore, Michael John Mott (from Graduate), Kenneth William Norris (from Graduate), Ivan James de la Plain, Leonard Redmayne, Charles Arthur Robinson (from Associate), Arthur James Edward Thornton, Morton Eric Turner, David William Ricketts Vincent, Robert John Edward Walker, Duncan Fairlie Wilson (from Associate), Peter Frank Witherden (from Graduate).

Associates

Frederick Oliver Barrett, Hazel Florence Brookes (from Student), Thomas Wight Campbell, Dennis Stratton Carton, Gaganendra Chandra Datta (ex-Associate), Peter Mainwaring Dunstan, Douglas Somerville Fuller (from Student), Owen Desmond Arthur Charles Furlong (from Student), Eric William Goode, Tore Ragnar Gullstrand, Peter Myles Irwin, Leslie Edwin King, James McAvoy, Derek Moncrieffe Mackay (from Student), Denis Patrick McMahon, Peter Lewis Martin, Dennis Nolan-Neylan, Robert Mervyn Tricker Ollis, Ernest Belford Parsons, John Davidson Ratchford, John Hardman Rawcliffe, Vincent Mervyn Ambler Richardson, Satyendra Kumar Roy, William Basil Kenyon Searle, Wilfred Vincent Smythe, Adrian Frederick Rex Stedman (from Student), Ian Radnor Stephens, John Francis Victor Veillard, Alexander Millar Wylie.

Graduates

Sheikh Mukarram Ali, Reginald Albert Lloyd Arkell (from Student), Denis Walter Barnes, Norman Atherstone Hilton Barraud, Anthony James Barrett (from Student), Eric Brelsford, Bernard Caiger (from Student), Ronald Sidney Capewell, Jacob Alexander Bruce Cartmel (from Student), John Bradley Chaplin (from Student), Dennis Collins, Thomas Patrick Doherty, Kenneth Edgerton (from Student), Alan Howard Farrow, Brian William Firth (from Student), John Walter Flower, Arthur Sydney Forster, John Cecil Geering, Norman Michael Gemson (from Student),

Roger Henry Ernest Goodman, Bernard Stephen Hanson (from Student), William John Harbottle (from Student), Cecil John Hart, Richard John Herbert (from Student), Paul Alexander Hilton (from Student), William Rogers Hoskin, Cyril Gwynne Hughes (from Student), Michael Stewart Igglesden (from Student), Gautam Khosla, Simon Kugler (from Student), Arthur George Kurn, Ernest Theodore Labett, Richard Alvin Mathias Lewis (from Student), Jack Walter Lloyd, George Maitland (from Student), Eric Gyril Maskell (from Student), John Edward Ne[illegible]away (from Student), Peter Maurice William Noel (from Student), William Michael Geoffrey Owen, Geoffrey Keith Charles Pardoe (from Student), Jagdish Chandra Pathak, Clive Redmayne, John Roy Richardson (from Student), Rodney George Rose (from Student), Jeffrey Scoresby, Michael Edmund Lock Spanyol, Gordon Edwin Staples (from Student), John Herbert Stephens (from Student), Robert Walter Wilson Tennant, Philip Rupert Thompson, Alan Sydney Thurley (from Student), Edward Trim, Kenneth John Turner, Joseph Waters (from Student), Jack Victor Athelstane Welbourn, Albert Edward White, James Lanham Wildhaber (from Student), Alan Wilding, John Malcolm Williams (from Student), Sinclair Murdoch Wilson, Robert Francis Henry Woodberry (from Student), William Butler Wright, Desmond John Yabsley.

Students

Bernard George Ambrose, Peter Alfred Thomas Christopher, Robert Edward Finch, Alexander Henry Fraser-Mitchell, Ramond Lionel Gamlin, Lawrence Frank Gillard, George Kenneth Frank Green, Ronald Charles Harris, Volrath Holmboe, Dalbir Kumar Kapur, Bryan McHugh, Denis John Powell, Peter Henry Raymond, Gerard Raphael Soffe, John Robert Williams.

Companion

John Oliver Montanaro.

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the return of back numbers of the Journal from Group Captain F. Norton, *Fellow;* Squadron Leader L. J. West, *Associate Fellow;* and H. H. Smith, Esq., *Associate Fellow.*

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.c.20—Thermodynamics. Schmidt and Kestin. Clarendon Press. 1949.

B.a.386—Aeronautics, Heavier-than-Air Aircraft. Part II. M. J. B. Davy. H.M.S.O. 1949.

D.e.42—Kosten und Preise im Luftverkehr. H. zur Nieden. Rascher Verlag. 1949.

E.b.142—Mechanics, Statics and Dynamics. M. Scott. McGraw Hill. 1949.

E.c.36—Theory of Notch Stresses. H. Neuber. J. W. Edwards. 1946.

E.h.11—Introduction to Production Control. D. Tiranti and W. Walker. Chapman and Hall. 1946.

EE.b.99—The Airplane and its Engine. Chatfield, Taylor and Ober. 5th Edition. McGraw Hill. 1949.

G.a.88—Aircraft Materials and Processes. G. F. Titterton. 3rd Edition. Pitman, New York. 1947.

I.a.41—Mathematics and the Imagination. E. Kaiser and J. Newman. G. Bell & Sons Ltd. 1949.

I.b.25—Advanced Calculus for Engineers. F. B. Hildebrand. Prentice Hall. 1949.

M.a.36—Ultrasonics. Benson Carlin. McGraw Hill. 1949.

N.a.102—Energy and Matter. R. L. Worrall. Staples Press. 1948.

N.d.10—Constructive Uses of Atomic Energy. S. C. Rothmann (Ed.) Harper and Bros. 1949.

S.d.101—Strategic Air Power for Dynamic Security. S. J. Possony. Infantry Journal Press. 1949.

N.A.C.A. Technical Memoranda

1110—*On combustion in a turbulent flow. K. I. Shelkin.*

1197—*Investigation on the stability, oscillation and stress conditions of airplanes with tab control. First Partial Report—Derivatives of the equations of motion and their general solutions. B. Filzek.*

1198—*Investigation on the stability, oscillation and stress conditions of airplanes with tab control. Second Partial Report—Application of the solutions obtained in the first partial report to tab-controlled airplanes. B. Filzek.*

1227—*Moments of cambered round bodies. Gunther Kempf.*

1228—*Behaviour of the laminar boundary layer for periodically oscillating pressure vibration. A. W. Quick and K. Schroder.*

1231—*Report on investigation of developed turbulence. L. Prandtl.*

1253—*Flow measurement by means of light interference. TH. Zobel.*

N.A.C.A. Reports

869—*Isolated and cascade airfoils with prescribed velocity distribution. A. W. Goldstein and M. Jerison.*

870—*Tank investigation of a powered dynamic model of a large long-range flying boat. J. B. Parkinson, R. E. Olsen and M. I. Haar.*

872—*Theoretical study of air forces on an oscillating or steady thin wing in a supersonic main stream. I. E. Garrick and S. I. Rubinov.*

875—*Application of the analogy between water flow with a free surface and two-dimensional compressible gas flow. W. J. Orlin, N. J. Lindner and J. G. Bitterly.*

877—*Summary report on the high-speed characteristics of six model wings having N.A.C.A. 65-series sections. W. T. Hamilton and W. H. Nelson.*

881—*Effect of combustor-inlet conditions on performance of an annular turbojet combustor. J. H. Childs, R. J. McCafferty and O. W. Surine.*

882—*Frequency-response method for determination of dynamic stability characteristics of airplanes with automatic controls. H. Greenberg.*

883—*Flight measurements of the lateral control characteristics of narrow-chord ailerons on the trailing edge of a full-span slotted flap. R. H. Sawyer.*

884—*Effects of sweep-back on boundary layer and separation. R. T. Jones.*

886—*Spark-timing control based on correlation of maximum-economy spark-timing, flame-front travels and cylinder-pressure rise. H. A. Cook, O. H. Heinicke and W. B. Haynie.*

887—*Critical stress of thin-walled cylinders in axial compression. S. B. Batdörf, M. Schildcrout and M. Stein.*

889—*Volterra's solution of the wave equation as applied to three-dimensional supersonic airfoil problems. M. A. Measley, H. Lomax and A. L. Jones.*

890—*Investigations of effects of surface temperature and single roughness elements on boundary-layer transitions. H. W. Leipmann and G. F. Fila.*

2325—*The effect of tension on the porosity of a parachute fabric. W. D. Brown.*

2331—*A method of estimating the effect of aero-elastic distortion of a swept-back wing on stability and control derivatives. H. M. Lyon.*

2332—*Note on two-dimensional supersonic tunnel interference. W. F. Hilton.*

A.R.C. Reports and Memoranda

2242—*A theoretical discussion of high-lift aerofoils with leading-edge porous suction. B. Thwaites.*

2252—*Profile drag measurements of compressibility speeds on aerofoils with and without spanwise wires or grooves. H. H. Pearcey.*
Note on Reynolds and Mach number effects on the pressure distribution on the tail of EC1250. J. A. Beavan.

2272—*The response of an aeroplane to the application of ailerons and rudders. Part II.—Response in yaw and sideslip. R. W. Gandy.*

2300 (Monograph)—*The investigation of aircraft accidents involving airframe failure. J. B. B. Owen and F. Grinsted.*

2304—*Preliminary measurements of the boundary layer in the* 11-*in. supersonic wind tunnel. W. F. Cope and G. G. Watson.*

2309—*The susceptibility of some parachute textiles to micro-biological attack. F. Millard.*

Nationaal Luchtvaartlaboratorium, Amsterdam

F.54—*Theory of the oscillating wing with aerodynamically balanced control surface in a two-dimensional, subsonic, compressible flow. R. Timman and A. I. van de Vooren.*

A.950—*Drag and pressure measurements with plaster spheres in wind tunnel* 3 *and* 4 *of the National Aeronautical Research Institute. Ir. S. I. Wiselius.*

A.1011—*Some remarks about high-frequency rotary-current electric motors for driving model propellers. J. G. Slotboom.*

J. LAURENCE PRITCHARD,
Secretary.

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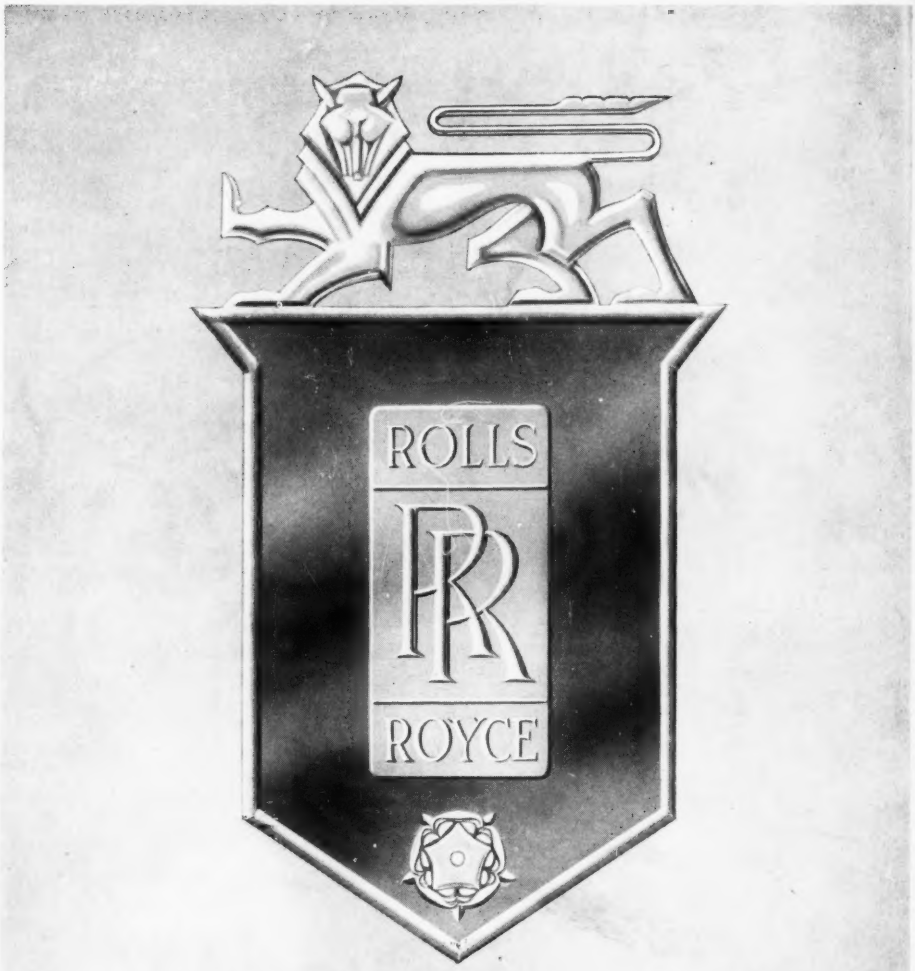
Heart of the 'Goblin'



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